LEVEL II (40)

PROCEEDINGS

AUVS '79

SIXTH ANNUAL CONVENTION

ASSOCIATION FOR UNMANNED VEHICLE SYSTEMS

AUVS
ASSOCIATION
ESTABLISHED 1972
FORMERLY NARPV

"AGE OF UNMANNED WARFARE"

1979

HOTEL DEL CORONADO
NAVAL AMPHIBIOUS BASE
SAN DIEGO, CALIFORNIA

79 12 6 130

CUBIC CORPORATION
Defense Systems Division

9233 Balboa Ave. • Post Office Box 80787
San Diego, CA 92138

December 4, 1979

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Attn: James Shafer DTIC/DPA
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411 495 Nav

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Sincerely,

Ed Salked

cc: W. Karmizan
B. Henz

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AUVS '79

SIXTH ANNUAL CONVENTION (6th)

ASSOCIATION FOR UNMANNED VEHICLE SYSTEMS

(12) 164

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ASSOCIATION
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"AGE OF UNMANNED WARFARE"

(11) **1979**

HOTEL DEL CORONADO
NAVAL AMPHIBIOUS BASE
SAN DIEGO, CALIFORNIA

411 495

PROCEEDINGS

ASSOCIATION

FOR

UNMANNED VEHICLE SYSTEMS

San Diego, California
May 29 - June 1, 1979

UNMANNED VEHICLES ON THE TACTICAL BATTLEFIELD

ANOTHER BEGINNING

Dr. William J. Whelan
The Rand Corporation
Santa Monica, California

UNMANNED VEHICLES ON THE TACTICAL BATTLEFIELD ANOTHER BEGINNING

Dr. William J. Whelan
The Rand Corporation
Santa Monica, California

INTRODUCTION

The Rand Corporation is currently under contract to the Defense Advanced Research Projects Agency (DARPA) for exploratory studies and analyses of distributed tank system concepts. These concepts are another example of enhancing the capabilities of a manned system by unmanned, highly automated subsystems. The word "distributed" is used to convey the idea of dispersed but interconnected subsystems.

Previous Rand study efforts for the DARPA Tactical Technology Office led directly to the present concepts development activity. These earlier efforts included examinations of the regeneration of damaged and/or failed combat vehicles on the conventional battlefield and analyses of several distributed tactical weapons systems concepts.

The Rand FY 1979 project is intended to be part of a larger related DARPA technology demonstration program.

SYNOPSIS

This paper addresses briefly the topics shown in Figure 1. Some brief remarks on the history and problems of unmanned ground vehicle systems are followed by an overview of distributed tactical weapon systems. The overview identifies some distributed systems, their major features and significant operational and R&D issues. Distributed tank systems concepts are considered next in the context of near- and far-term time periods. A specific near-term distributed tank system concept, namely, TEARS is discussed in greater detail. The TEARS concept is the major theme of this paper and the Rand research effort. The paper concludes with a description of the Rand analytical activities and the proposed DARPA program schedule.

HISTORY OF UNMANNED MILITARY GROUND VEHICLE SYSTEMS (Figure 2)

During World War II several unsuccessful attempts were made to develop and employ unmanned ground combat vehicles. The Germans, in particular, developed and operated small, robot tank systems. These vehicles did not fare well and have been condemned to the annals of World War II curiosities. Since 1945, there has been a miscellany of R&D projects by a handful of countries in an attempt to realize unmanned ground combat vehicles. Most projects were short-lived, all were essentially unsuccessful. There are no unmanned ground combat vehicles in the inventory of any army and none programmed or planned for the U.S. Army.

A review of documented R&D efforts reveals two major common and related shortcomings. Nearly all efforts suffered from inadequate analyses of tactical requirements for and potential contributions by unmanned vehicles. A general assumption was that unmanned ground combat vehicles were not only desirable but very useful across many applications. The second shortcoming was the resulting and inappropriate emphasis on vehicle mobility and control. These features of unmanned combat vehicle systems received the greatest amount of R&D attention and funds, to the detriment of the entire system.

Yet, each of these R&D efforts made its contribution, if only to help certify that unmanning ground combat vehicles would be an extremely difficult technological as well as operational task.

DISTRIBUTED TACTICAL WEAPON SYSTEM CONCEPTS

These concepts are defined in Figure 3 and examples are provided in Figure 4. All of these examples are successfully developed distributed weapons systems. The idea of considering some of these examples as distributed systems may seem strange but they all involve the enhancement of a manned system by unmanned, dispersed and interconnected subsystems. The cruise missile, a favorite of unmanned system advocates, is in reality a disbursed subsystem of a larger manned system.

The general features of distributed tactical weapons systems are shown in Figure 5 in terms of selected major attributes and their potential tactical or operational exploitations. Most of these attributes are achieved by removing the man from the disbursed subsystem. The value of these attributes will continue to increase as more design, technology development, and engineering resources are applied to unmanned subsystems. The tactical exploitations of these attributes are known but not yet well understood or exercised. Operational practice and experience must be accumulated and studied to provide usable tactical deployment and employment concepts.

Several major operational and R&D issues for distributed tactical weapons systems are listed in Figure 6. These topics remain viable issues since they relate directly to known limitations, problem areas or areas in which advanced technologies could have major impacts on capabilities.

DISTRIBUTED TANK SYSTEM CONCEPTS

It is a short step from distributed tactical weapons systems to distributed tank systems concepts (see Figure 7). All of the previous discussion regarding distributed system features and issues applies to distributed tank systems. In addition, several more pertinent features are noted in Figure 8. The last idea presented in Figure 8 suggests that the next generation (post XM-1) of tank systems could be a distributed tank system. The expected advancement of component technologies throughout the next few decades should provide this option to future tank system designers. To insure that this option will be available it is prudent now to begin to explore distributed tank system concepts. It is not too early to begin to understand the operational capabilities and related R&D activities essential to achieve distributed tank systems.

Figures 9 and 10 point out the general state of knowledge of distributed tank system concepts. Also, that near-term distributed tank systems will probably be based on augmenting present and programmed tank systems and lay the groundwork for an orderly progression to far-term concepts.

TANK EFFECTIVENESS AUGMENTATION BY REMOTE SUBSYSTEMS (TEARS)*

The basic concept and purpose of augmenting present or programmed tank systems with remote subsystems are shown in Figure 11. The assertion made in the purpose statement (and amplified in succeeding paragraphs) is that distributed tank systems will provide major increases in tank system effectiveness for marginal increases in resource costs.

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*Named after the dramatic reaction of various combat vehicle experts to the concept, i.e., laughter or crying.

The rationale presented in skeletal form in Figure 12 considers the current critical threat problems confronting the NATO tank forces and systems and the value of these systems to the combined arms force and NATO strategy. The factors listed in Figure 12 suggest trends which are making the problems worse or presenting only marginal solutions.

Several major criteria for distributed tank systems are presented in Figure 12. These criteria, not necessarily in order, are that remote subsystems must (1) be capable of neutralizing enemy armor and antiarmor systems (increased tank firepower), (2) be able to move or be moved long distances faster than tanks (increased firepower mobility), and (3) allow tanks to better utilize cover and concealment (increased tank survivability). Further criteria for a TEARS are listed in Figure 13. These additional criteria are derived from the general criteria and the idea that a tank must not have its capability as a combat vehicle degraded by the augmenting subsystem.

Figures 14, 15, and 16 contain the results of preliminary analyses of the TEARS concept. These early results are meant to (1) guide further analyses, (2) provide initial design guidance for tank system designers, (3) indicate those characteristics which any simulated TEARS should have, and (4) help identify operational issues as well as shape field experiments and tests.

Figures 17 and 18 show an artist's conception of the TEARS and its remote subsystem (DEMON).* Two modes of employment are illustrated in Figure 17. At longer ranges (perhaps 2-4 kilometers) the DEMON searches, acquires and engages advancing enemy combat vehicles while under control of the augmented and concealed tank. When enemy combat vehicles close to shorter ranges (1 km or less), the DEMON is switched to an automatic acquisition and engagement mo[illegible] freeing the augmented tank to enter the fight or move to an alternate position.

The DEMON configurations shown in Figure 18 are again an artist's conception of three stages of its operation. The low observables configuration indicates the DEMON presenting its lowest visible signatures; the long range fire configuration shows the target search and acquisition sensor package extended; and the short range fire configuration suggests a weapon launch tube erected horizontally for terminal guidance lock-on before firing.

More potential advantages of TEARS are listed in Figure 19. These advantages suggest further tactical or operational exploitations of distributed tank system characteristics and capabilities.

Some of the critical and other major issues facing the TEARS concept are displayed in Figures 20 and 21. Several of these issues may be resolved by analyses, but most cannot be since they depend on operational factors difficult to analyze. Also, some of these issues require detail design information and tactical deployment and employment descriptions for meaningful analyses.

GENERAL APPROACH AND SCHEDULE FOR TEARS

Figure 22 shows a proposed general schedule for the TEARS program. At the present time Rand and the U.S. Army Armaments R&D Command are involved in the FY 1979 analytical and technological assessment activities. The basic approach is to use these continuing studies and analyses plus field experiments with a

---

*The classical evil spirit who, in some cultures, is the malevolent disembodied human soul of someone who died a violent death lying in wait in unexpected places.

simulated TEARS to provide sufficient design guidance for design and fabrication of a demonstration system. The schedule is optimistic and dependent on continued funding.

The role of The Rand Corporation is briefly described in Figure 23. The operational criteria analyses are employing various methodologies developed at Rand. The most significant of these methodologies is our Manually Aided Gaming of Integrated Combat (MAGIC) system. MAGIC is a terrain board, computer-aided game allowing focus on individual weapons systems within simulated force on force engagements. A unique feature of MAGIC is its ability to delineate clearly the objective and subjective features of an innovative weapons system and their impact on battlefield capabilities.

There has been no discussion of mobility of the remote subsystem. However, two kinds of mobility are being examined, namely, cross battlefield and local mobility. Self-mobility remains an open question and perhaps will be so until selected field experiments and specific designs have been accomplished.

I look forward to presenting the results of our first year's effort at the AUVS symposium next year.

SYNOPSIS

- UNMANNED MILITARY GROUND VEHICLE SYSTEMS
- DISTRIBUTED TANK CONCEPTS
- TEARS
- CURRENT DARPA PROGRAM
- RAND ROLE AND ACTIVITIES

Figure 1

UNMANNED MILITARY GROUND VEHICLE SYSTEMS

HISTORY/PROBLEMS

- WORLD WAR II (AND EARLIER) ATTEMPTS
- MISCELLANY OF R&D PROJECTS

- REQUIREMENTS AND PAYOFFS ANALYSES
- EMPHASIS ON VEHICLE MOBILITY AND CONTROL

Figure 2

DISTRIBUTED TACTICAL WEAPON SYSTEM CONCEPTS

UNMANNED, HIGHLY AUTOMATED, MOBILE / MOVABLE,
SEARCH, ACQUISITION AND ENGAGEMENT SUBSYSTEMS
CONTROLLED AND / OR INITIATED BY REMOTE AND
MANNED COMMAND CENTERS

Figure 3

DISTRIBUTED TACTICAL WEAPON SYSTEMS

EXAMPLES

DISTRIBUTED AIRCRAFT SYSTEMS →

- CRUISE MISSILES
- REMOTELY PILOTED VEHICLES

DISTRIBUTED ARTILLERY SYSTEMS →

- PRECISION GUIDED MUNITIONS
- UNATTENDED GROUND SENSORS
- MINES

Figure 4

DISTRIBUTED TACTICAL WEAPONS SYSTEMS

FEATURES

ATTRIBUTES		TACTICAL EXPLOITATIONS
• EQUAL/GREATER CAPABILITIES WITH LOWER MANPOWER COSTS		• SYNERGISTIC FORCE INCREASES
• HIGHER ATTRITION TOLERABLE	→	• CENTRALIZED CONTROL
• LOWER SIZE, WEIGHT, OBSERVABLES		• FORCE MIX OPTIONS
• GREATER READINESS AND AVAILABILITY		• FORCE DEPLOYMENT/EMPLOYMENT OPTIONS
		• STANDARDIZATION AND INTER-OPERABILITY

Figure 5

DISTRIBUTED TACTICAL WEAPONS SYSTEMS

ISSUES

- INFORMATION/INTELLIGENCE
- COMMAND, CONTROL AND COORDINATION
- MAN-MACHINE INTERFACES AND INTERACTIONS
- ELECTRONIC VULNERABILITIES
- TECHNOLOGICAL IMPLEMENTATIONS
- OBSOLESCENCE

Figure 6

DISTRIBUTED TANK CONCEPTS

NETWORKS OF INTERACTIVE, UNMANNED, HIGHLY AUTOMATED MOBILE/MOVABLE, SEARCH, ACQUISITION AND ENGAGEMENT SUBSYSTEMS CONTROLLED BY MOBILE MANNED COMMAND CENTERS

Figure 7

DISTRIBUTED TANK CONCEPTS

FEATURES

- HIGH TECHNOLOGY/LOW MANPOWER NETWORK(S) IN WHICH SUBSYSTEMS CAN FUNCTION TOGETHER IN VARIOUS MODES TO PROVIDE
  - HORIZONTAL/VERTICAL SEARCH, ACQUISITION AND ENGAGEMENT OF TACTICAL TARGETS
  - FIREPOWER MOBILITY
  - HIGH SURVIVABILITY OF NETWORK CAPABILITIES
- POSSIBLE FOLLOW-ON TO PROGRAMMED TANK FORCES

Figure 8

DISTRIBUTED TANK CONCEPTS

NEAR TERM (5-15 YEARS)

- AUGMENTATION OF PRESENT/PROGRAMMED TANK SYSTEMS
- SOME CONCEPTS KNOWN AND UNDER STUDY (TEARS)
- SPECIFIC SUBSYSTEMS NEED TO BE IDENTIFIED, DESIGNED, FABRICATED AND TESTED
- CONCEPT DEFINITION STUDIES, ANALYSES AND EXPERIMENTS REQUIRED TO UNCOVER CRITICAL TECHNOLOGICAL, ENGINEERING AND OPERATIONAL PROBLEMS

Figure 9

DISTRIBUTED TANK CONCEPTS

FAR TERM (15-30 YEARS)

- SOME GENERAL CONCEPTS KNOWN
- NO RESTRICTION TO PROGRAMMED SYSTEMS AND AUGMENTATION THEME
- DEPENDENT ON NEW AND ADVANCED TECHNOLOGIES BUT SHAPED BY NEAR TERM CONCEPT DEVELOPMENT

Figure 10

TEARS

BASIC CONCEPT

- PRESENT/PROGRAMMED TANK SYSTEM USED AS CENTRAL COMMAND CENTER FOR INTERCONNECTED, REMOTELY LOCATED, UNMANNED, SEARCH, ACQUISITION AND ENGAGEMENT SUBSYSTEMS

PURPOSE

- AUGMENT TANK FORCE BY PROVIDING MAJOR INCREASES IN FIREPOWER, MOBILITY AND SURVIVABILITY

Figure 11

TEARS

RATIONALE

- TANK FORCE IS KEY FIREPOWER/MOBILITY ELEMENT OF U.S. ARMY COMBINED ARMS TACTICS AND KEY FACTOR IN U.S./NATO ANTI-WARSAW PACT STRATEGY
- U.S. TANK FORCE IS DRASTICALLY OUTNUMBERED AND STRESSED (SEVERE ANTI-TANK THREATS)

CURRENT PRESSING QUESTION

HOW TO GET MAJOR INCREASES IN FIREPOWER, MOBILITY AND SURVIVABILITY OF INDIVIDUAL TANKS IN MID-RANGE PERIOD?

FACTORS

- TANK PROCUREMENT AND O&M COSTS IMPEDE TANK FORCE EXPANSION
- TANKS HAVE LOW FIREPOWER/MANPOWER RATIOS
- CROSS-BATTLEFIELD MOBILITY OF TANKS LIMITED
- ADVANCES IN TANK DESIGN (ARMOR, PROPULSION, ARMAMENT) IMPORTANT BUT DON'T OFFER MAJOR INCREASES

Figure 12

TEARS

CRITERIA

- MINIMUM INTERFERENCE WITH TANK SYSTEM DESIGN, CONFIGURATION AND OPERATION
- REMOTE SUBSYSTEMS MUST BE LIGHTWEIGHT (HELICOPTER TRANSPORTABLE), HIGHLY AUTOMATED (MINIMUM BURDEN ON TANK CREW), EASILY SET UP AND COST CONSIDERABLY LESS THAN TANK
- INTERCONNECTIONS MUST BE RELIABLE, SECURE, EASILY ATTACHED DETACHED
- SUBSYSTEMS DESIGNED FOR LIMITED COMBAT LIFE (EXPENDABLE)

Figure 13

TEARS

PRELIMINARY ANALYSES (DIMENSIONS)

- NO LARGER THAN TANK ($30\ m^2 \times 2\ m$)
- LIGHTLY ARMORED
- WIDE, LOW SHAPE
- LIGHT WEIGHT
- VARIABLE CONFIGURATIONS

- DIFFICULT TO DETECT, TARGET, HIT AND KILL (SELECTED RESEMBLANCES TO TANK)
- LOW VULNERABILITY TO FRAGMENTS AND SMALL ROUNDS
- MINIMUM VULNERABILITY TO BLAST (DIRECT HIT TO KILL)
- HELICOPTER TRANSPORTABLE (< 3-4 TONS)
- LOW OBSERVABLES (INCREASED SENSOR WEAPON CAPABILITIES)

Figure 14

TEARS

PRELIMINARY ANALYSES (SENSORS/WEAPONS)

- DIRECT / INDIRECT FIRE
- MIXED WARHEADS
- AUTO { WEAPON SELECTION, LOADING & FUZING, FIRING
- IR & VISIBLE & PERHAPS RADAR
- ERECTABLE SENSOR CARRIAGE AND LAUNCHERS

- ACTIVE HOMING 40 m - 4000 m
- ANTI-ARMOR, ANTI-PERSONNEL
- FIRING RATE ~ TANK + RIPPLE & SALVO FIRE
- NIGHT, SMOKE, MIST, RAIN
- WIDE, LONG FIELDS OF VIEW AND FIRE

Figure 15

TEARS

PRELIMINARY ANALYSES (COSTS)

- < 1/4 COST OF TANK
- COMPARABLE IN COST TO TOW SYSTEM
- PREMIUM ON RELIABILITY, LONG STORAGE LIFE, AND RAPID ACTIVATION
- NO DEDICATED MANPOWER OR FACILITIES SUPPORT
- REUSABLE STRUCTURE

Figure 16

TEARS

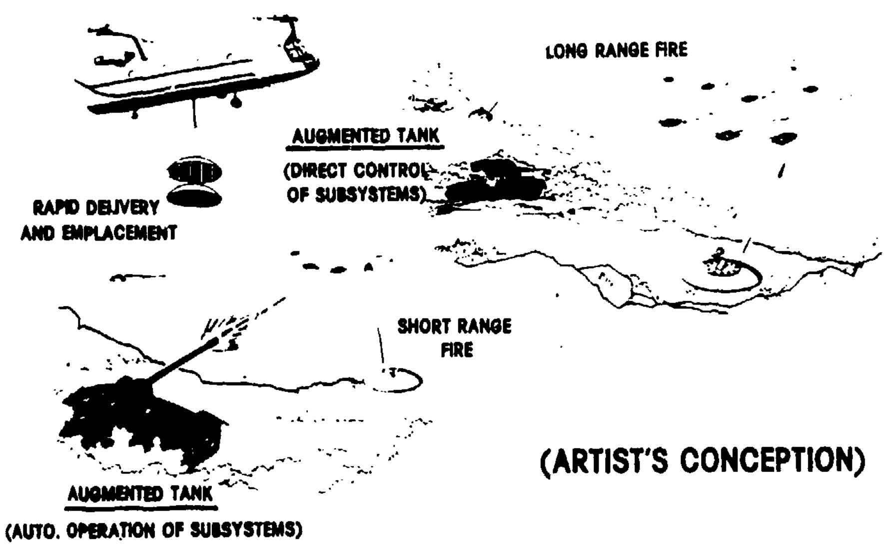


Figure 17

TEARS

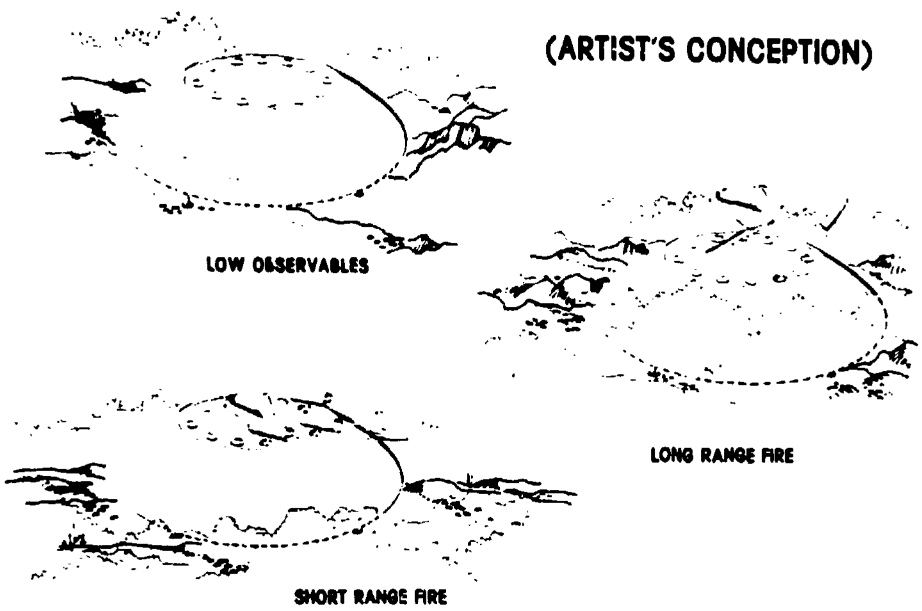


Figure 18

MORE POTENTIAL ADVANTAGES OF TEARS

- PROVIDE TANK WITH CONTROL OVER OFFSET SUPPORTING AND FLANKING WEAPONS
- PROVIDE TANK WITH MISSILE CAPABILITY WITHOUT HAVING MISSILE ON TANK
- ALLOW TANK INCREASED OPTIONS TO COMMIT TO ENGAGEMENT OR MOVE TO ALTERNATE POSITION(S)
- PROVIDE COVERING FIRE FOR CROSSING RIVERS OR OPEN AREAS, AND OTHER OFFENSIVE MANEUVERS

Figure 19

TEARS

SOME CRITICAL ISSUES

- MAN/MACHINE INTERFACES AND INTERACTIONS
  - DISPLAY HARDWARE, FORMAT(S), CONTROL
  - CONTROL INPUTS, INTERACTIVE FEATURES
  - COGNITIVE LOAD
  - DECISION AIDS
  - LOCAL/CENTRAL AUTONOMY
- COMMUNICATIONS
  - BANDWIDTHS
  - SPECTRAL CONTROL
  - MODES
  - SECURITY
  - LANGUAGE/PROTOCOLS

Figure 20

TEARS

SOME MAJOR ISSUES

- TANK/REMOTE SUBSYSTEM EMPLOYMENTS/DEPLOYMENTS
  - SUBSYSTEM FUNCTIONS, NUMBERS, LOCATIONS
  - TANK CREW CAPABILITIES
  - COMMAND, CONTROL, COMMUNICATIONS MODES
  - IM-, RE- AND EXPLACEMENT OF SUBSYSTEMS
- REMOTE SUBSYSTEM CONFIGURATION(S)
  - SENSORS
  - WEAPONS
  - MOBILITY FEATURES
  - PROTECTION
  - AUTOMATION

Figure 21

TEARS

GENERAL APPROACH AND SCHEDULE

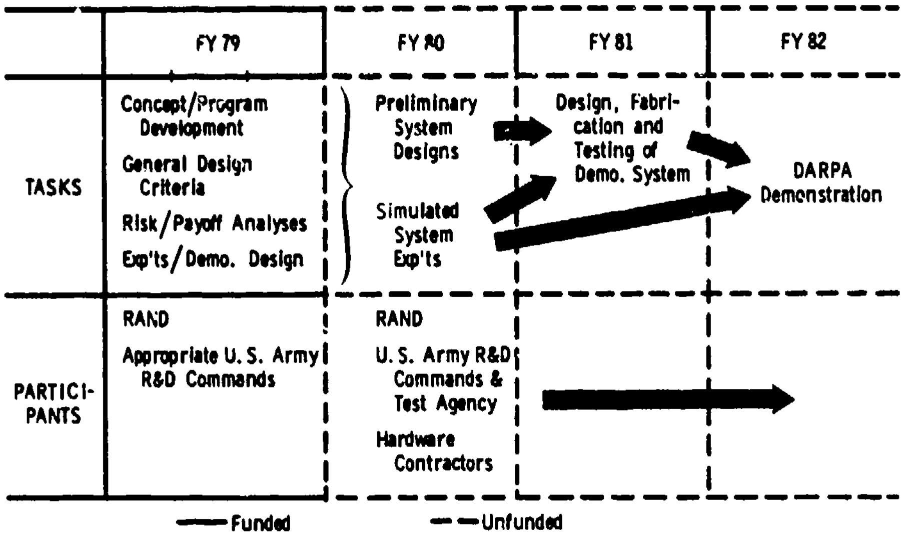


Figure 22

RAND ACTIVITIES

- TEARS OPERATIONAL CRITERIA ANALYSES
  - MANUALLY AIDED GAMING OF INTEGRATED COMBAT (MAGIC)
  - FIELDS OF VIEW, FIRE, REACTION, ENGAGEMENT TIMES, ETC.
- SENSOR, WEAPON, INTERCONNECTION TECHNOLOGY ANALYSES
  - MULTI-SENSOR INTEGRATION
  - POWER AND DATA REQUIREMENTS
  - TANK MODIFICATIONS
- PROGRAM GUIDANCE AND DEVELOPMENT
  - SCHEDULE, TASKS, CAPABILITIES
  - LIAISON WITH U.S. ARMY COMMANDS

Figure 23

AUVS-79 SYMPOSIUM
"AGE OF UNMANNED WARFARE"

WHY UNMANNED VEHICLES CAN BE EFFECTIVE

30 May 1979

Ralph MacKenzie
Vice President, General Dynamics Convair Division

GENERAL DYNAMICS
Convair Division

23059433-01

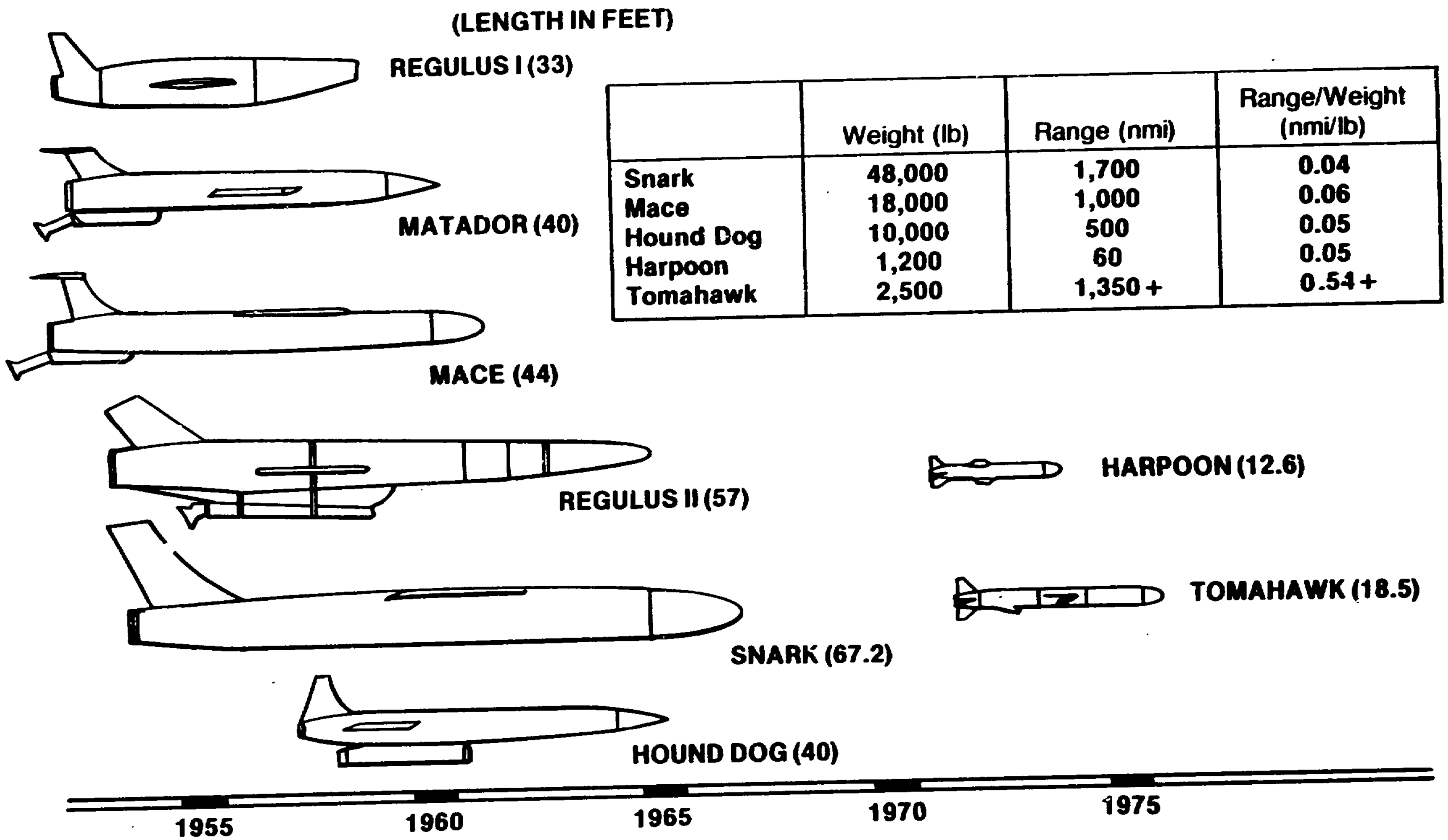
INTRODUCTION

TECHNOLOGICAL ADVANCES IN RECENT YEARS HAVE BROUGHT ABOUT A VIRTUAL REVOLUTION IN THE PERFORMANCE CAPABILITIES AND EFFECTIVENESS OF UNMANNED VEHICLES. UNMANNED SYSTEMS OF MOST TYPES, AND UNMANNED AIR VEHICLES IN PARTICULAR, HAVE BECOME COMPETITIVE WITH MANNED SYSTEMS. PERHAPS THE BEST EXAMPLE OF THIS, AND THE ONE RECEIVING THE MOST ATTENTION TODAY, IS THE LONG-RANGE CRUISE MISSILE. BECAUSE OF MY EXPERIENCE WITH THE TOMAHAWK CRUISE MISSILE, I WILL FOCUS ON THIS SYSTEM ALTHOUGH MANY OF THE TECHNOLOGICAL ADVANCEMENTS APPLY TO OTHER UNMANNED SYSTEMS.

UNITED STATES
CRUISE MISSILES

CRUISE MISSILES HAVE BEEN AROUND FOR A LONG TIME. THEY WERE FIRST SERIOUSLY DEPLOYED BY THE UNITED STATES IN THE EARLY 1950s AND ON INTO THE 1960s. BALLISTIC MISSILES THEN TOOK PREEMINENCE IN U.S. OFFENSIVE MISSILE CAPABILITIES. IT WASN'T UNTIL THE EARLY 1970s IN THIS COUNTRY THAT CRUISE MISSILES, SUCH AS TOMAHAWK, TAKING ADVANTAGE OF TECHNOLOGICAL ADVANCES THAT I WILL DISCUSS, BECAME COST-EFFECTIVE AND COMPETITIVE WITH OTHER MISSILES AND MANNED SYSTEMS. THE DRAMATIC IMPROVEMENT IN THE RANGE-TO-WEIGHT RATIO SHOWN ON THE CHART IS PARTICULARLY INTERESTING. IF WE LOOK AT SOVIET CRUISE MISSILES, WE SEE THAT THEIR RANGE-TO-WEIGHT RATIOS ARE STILL THE SAME AS OUR OLDER CRUISE MISSILES. HOWEVER, UNLIKE THE UNITED STATES, THE SOVIETS CONTINUED TO EMPLOY BOTH CRUISE MISSILES AND BALLISTIC MISSILES.

UNITED STATES CRUISE MISSILES

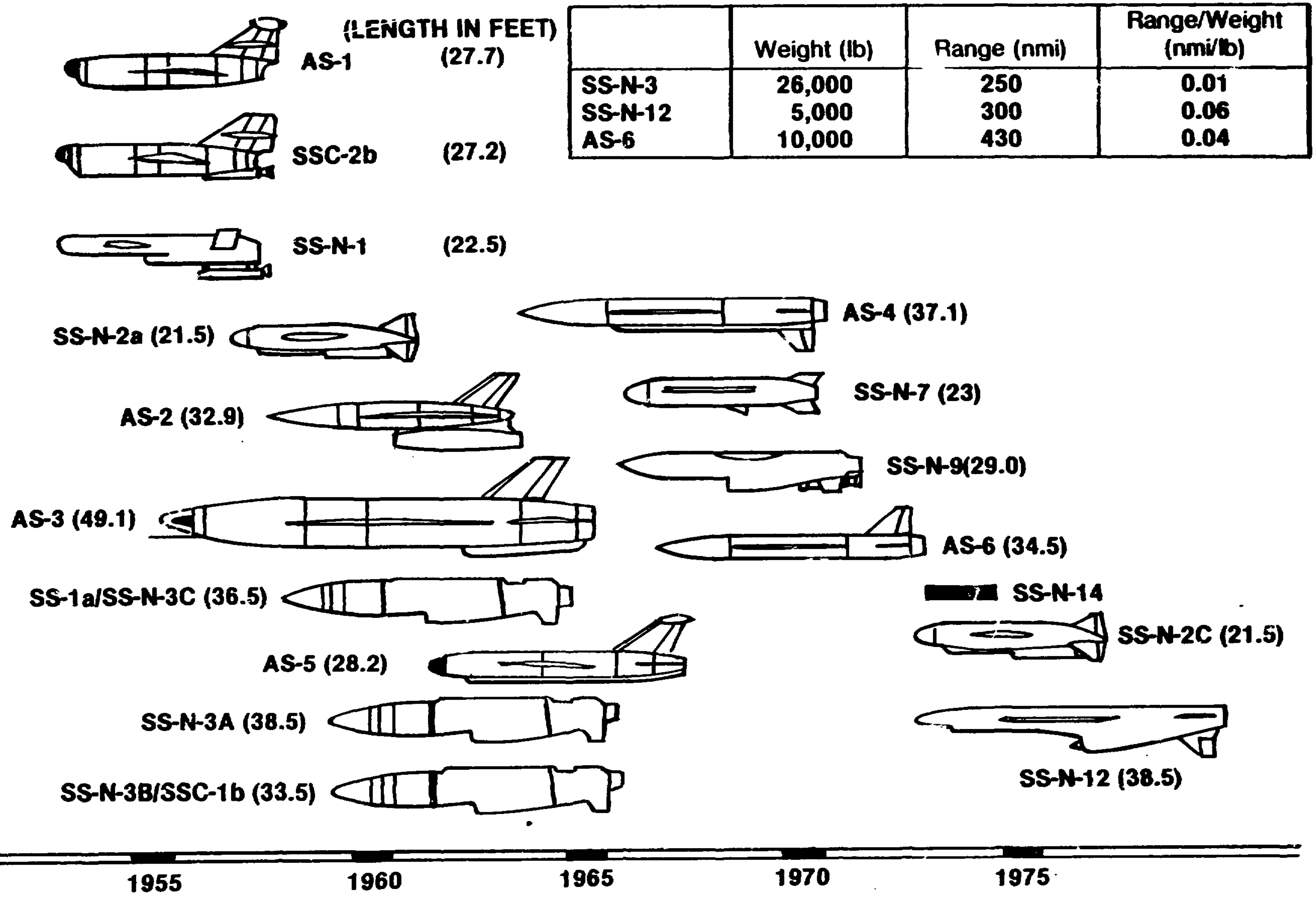


	Weight (lb)	Range (nmi)	Range/Weight (nmi/lb)
Snark	48,000	1,700	0.04
Mace	18,000	1,000	0.06
Hound Dog	10,000	500	0.05
Harpoon	1,200	60	0.05
Tomahawk	2,500	1,350 +	0.54 +

23059433-03

SOVIET CRUISE MISSILES

	Weight (lb)	Range (nmi)	Range/Weight (nmi/lb)
SS-N-3	26,000	250	0.01
SS-N-12	5,000	300	0.06
AS-6	10,000	430	0.04



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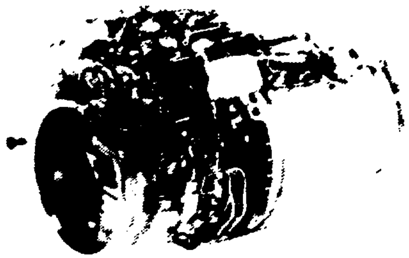
FOUR KEY TECHNOLOGICAL DEVELOPMENTS

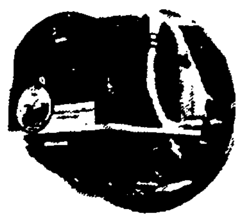
THERE HAVE BEEN FOUR MAJOR TECHNOLOGICAL ADVANCES WHICH HAVE MADE THE DEVELOPMENT OF MODERN U.S. LONG-RANGE CRUISE MISSILES POSSIBLE. THESE ARE SHOWN ON THE CHART. THE LAST POINT IS REALLY REFERRING TO LIGHTWEIGHT NUCLEAR WARHEADS. BUT CONVENTIONAL CRUISE MISSILE TECHNOLOGY HAS ALSO BENEFITED FROM IMPROVED CONVENTIONAL SUBMUNITIONS AND THE ABILITY TO PACKAGE LARGE NUMBERS OF THEM WITHIN A LIMITED VOLUME. I WILL DISCUSS FURTHER THE FIRST TWO OF THESE TECHNOLOGICAL ADVANCES, WHICH HAVE BEEN THE MOST SIGNIFICANT, AS WELL AS AN ADDITIONAL FACTOR, INNOVATIONS IN MANUFACTURING TECHNIQUES.

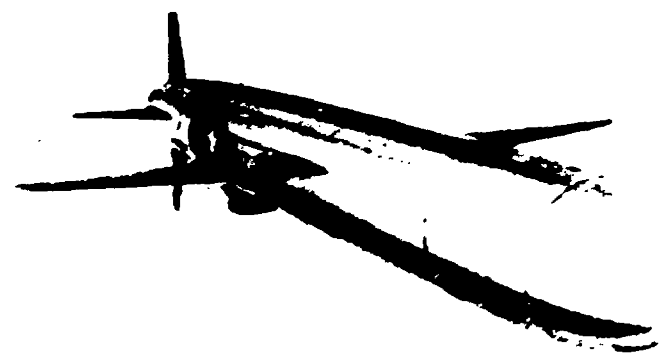
FOUR KEY TECHNOLOGICAL DEVELOPMENTS MAKE CRUISE MISSILE VIABLE & EFFECTIVE

1. Small, efficient turbofan engine — high bypass ratio



2. Microminiaturized electronics





3. Defense Mapping Agency
   Accurate guidance update source data

4. Small, high-yield warheads

23059433-04

ADVANCES IN CRUISE MISSILE ENGINE TECHNOLOGY

THE FIRST MAJOR TECHNOLOGY DEVELOPMENT WHICH HAS MADE MODERN U.S. CRUISE MISSILES POSSIBLE IS IN THE AREA OF PROPULSION SYSTEMS. IF YOU COMPARE THE CRUISE MISSILE ENGINES OF THE 1970s--SUCH AS THOSE ON HARPOON AND TOMAHAWK--WITH THOSE OF THE 1950s AND 60s YOU SEE MAJOR IMPROVEMENTS IN THRUST-TO-WEIGHT AND THRUST PER UNIT VOLUME (2-3 TIMES GREATER). THIS HAS PRIMARILY BEEN THE RESULT OF IMPROVEMENTS IN DESIGN, MATERIALS TECHNOLOGY, AND THE USE OF HIGH ENERGY FUELS. WHAT DISTINGUISHES THE TOMAHAWK WILLIAMS ENGINE FROM THE OTHER THREE ON THIS CHART IS THAT IT IS A FUEL EFFICIENT TURBOFAN ENGINE, WHILE THE OTHERS ARE ALL TURBOJETS. THE TURBOFAN, WITH ITS HIGH BYPASS RATIO, HAS A LOW SPECIFIC FUEL CONSUMPTION WHICH, COUPLED WITH LIGHTER GUIDANCE SYSTEMS AND WARHEADS, RESULTS IN TOMAHAWK'S MUCH GREATER RANGE-TO-WEIGHT RATIO COMPARED WITH EARLIER CRUISE MISSILES.

ADVANCES IN CRUISE MISSILE ENGINE TECHNOLOGY

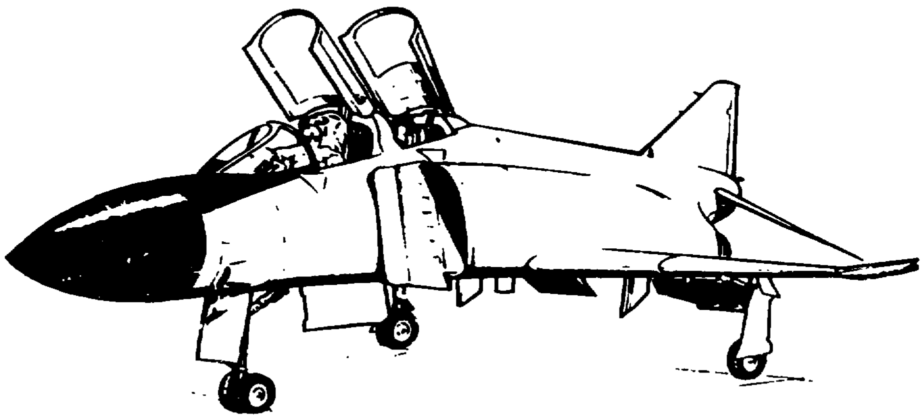
TYPE OF CRUISE MISSILE (DATE DEPLOYED)	ENGINE VENDOR & MODEL NO.	RATED THRUST (LB)	PHYSICAL DATA			KEY PERFORMANCE PARAMETERS		
			WEIGHT (LB)	DIA. (IN.)	LENGTH (IN.)	SFC (LB/HR/LB)	THRUST/WEIGHT	THRUST/UNIT VOLUME (LB/FT^3)
Snark (1958)	Pratt & Whitney J-57 (JT-3)	11,200	3,870	39	167	.80	2.89	24
Hound Dog (1961)	Pratt & Whitney J52-P-3	8,000	2,200	30	125	.80	3.64	39
Harpoon (1978)	Teledyne CAE J402-CA-400	660	98	12.5	27	1.17	6.73	86
Tomahawk	Williams Research F107-WR-100	630	103	12	29	.61	6.12	83

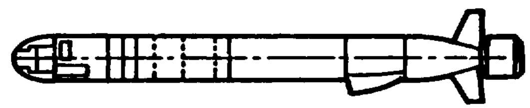
23059433-05

ADVANCES IN GUIDANCE TECHNOLOGY

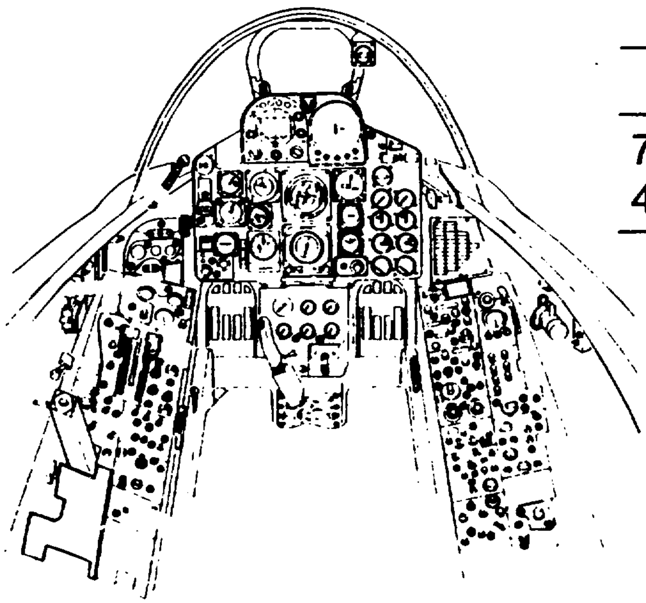
THE SECOND MAJOR TECHNOLOGY ADVANCE WHICH HAS MADE MODERN U.S. CRUISE MISSILES POSSIBLE IS THE DEVELOPMENT OF LIGHT-WEIGHT, MINIATURIZED GUIDANCE SYSTEMS EMPLOYING MICRO-PROCESSORS AND SENSORS, AND THE ACCURATE SOURCE DATA NEEDED TO OPERATE THIS SYSTEM. TOMAHAWK'S HIGH ACCURACY GUIDANCE SYSTEM IS A COMBINATION OF AN INERTIAL NAVIGATION PLATFORM AND A TERRAIN CONTOUR MATCHING UPDATING SYSTEM AND WEIGHS ABOUT 1/10 OF THE WEIGHT OF THE MISSILE. THE BASIC DIFFERENCE BEWEEN THE AVIONICS OF TOMAHAWK AND THE F-4 IS THAT THE CRUISE MISSILE IS FULLY AUTOMATED AND AUTONOMOUS, WHILE THE COMPLEX AVIONICS OF THE F-4 BASICALLY AMOUNT TO A GROUP OF INFORMATION SYSTEMS FOR A HUMAN DECISION-MAKER.

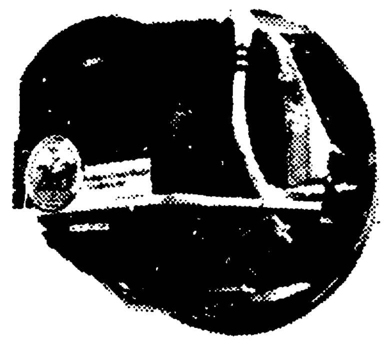
ADVANCES IN GUIDANCE TECHNOLOGY





AVIONICS		
F-4		TOMAHAWK
700	Wt (lb)	25
400K	Cost (FY79$)	180K





TERCOM (TERRAIN CONTOUR MATCHING)

23059433-06

ADVANCES IN MANUFACTURING METHODS

UNMANNED SYSTEMS TODAY ALSO BENEFIT FROM ADVANCES IN MANUFACTURING METHODS. OUR TOMAHAWK AND ALCM PROGRAMS AT CONVAIR HAVE DRAWN EXTENSIVELY ON STATE-OF-THE-ART ADVANCES, PARTICULARLY INNOVATIONS IN MACHINING, WELDING, AND MILLING TECHNIQUES, TO ACHIEVE PERFORMANCE-EFFICIENT AND COST-EFFECTIVE AIR VEHICLE DESIGNS. THREE MAJOR ADVANCES IN MANUFACTURING TECHNIQUES THAT WE ARE USING IN OUR CRUISE MISSILE FABRICATION, FOR EXAMPLE, ARE:

1) AUTOMATED, NUMERICAL CONTROL MACHINING
2) ELECTRON BEAM WELDING
AND 3) AUTOMATED INTERNAL MILLING

THESE IMPROVED PROCESSES MAKE IT POSSIBLE TO MANUFACTURE UNMANNED AIR VEHICLES WITH MUCH LESS MANPOWER AND AT LOWER COST AND RISK THAN WAS POSSIBLE WITH EARLIER TECHNIQUES

CONVENTIONAL CRUISE MISSILES - FORCE MULTIPLIER EFFECT

HAVING DISCUSSED THE SUBSTANTIAL IMPROVEMENTS IN THE PERFORMANCE CAPABILITY OF MODERN CRUISE MISSILES OVER EARLIER VERSIONS, I NOW WANT TO TALK ABOUT WHAT IS REALLY THE MOST IMPORTANT THING, THE PAYOFF THESE TECHNOLOGICAL IMPROVEMENTS OFFER IN TERMS OF OPERATIONAL EFFECTIVENESS.

WHILE DOD PLANS FOR DEPLOYING NUCLEAR MISSILES TODAY RECEIVE THE MOST ATTENTION, IT IS THE CONVENTIONALLY-ARMED CRUISE MISSILE WHICH MAY ULTIMATELY PROVIDE THE BIGGEST PAYOFF OF THESE TECHNOLOGIES, AND WHICH IS CURRENTLY THE MOST CONTROVERSIAL CRUISE MISSILE APPLICATION BECAUSE OF THE PERCEIVED COMPETITION WITH MANNED AIRCRAFT. IN THIS APPLICATION CRUISE MISSILES OFFER SIGNIFICANT BENEFITS IN TWO SCENARIOS:

1) TO GENERATE IMMEDIATE MASSIVE FIREPOWER (WHERE WE CAN NOT GENERATE SUFFICIENT AIRCRAFT SORTIES

AND 2) WHERE MANNED AIRCRAFT ATTRITION RATES ARE PROHIBITIVE

PERHAPS, THE BEST ILLUSTRATION OF THE FIRST APPLICATION IS THE POTENTIAL IMPACT WHICH WOULD RESULT FROM ADDITING CONVENTIONAL CRUISE MISSILES TO OUR NATO FORCES IN EUROPE. STUDIES WHICH WE HAVE DONE AT CONVAIR HAVE INDICATED THAT THE INTRODUCTION OF ONLY 1500 CONVENTIONAL AIRFIELD ATTACK CRUISE MISSILES COULD HAVE A DECISIVE IMPACT ON THE OUTCOME OF A EUROPEAN CONFLICT.

USING A PROJECTED 1985 FORCE MIX, THE RESULTS SHOW THAT THE WARSAW PACT ACHIEVES A SIGNIFICANT ADVANTAGE IN THE AIR WAR WHEN NO CRUISE MISSILES ARE AVAILABLE TO NATO FORCES. WHEN THE 1500 CRUISE MISSILES ARE ADDED TO THE SCENARIO AND LAUNCHED DURING THE FIRST 2 DAYS OF THE WAR AGAINST WARSAW PACT AIRFIELDS, THE SITUATION UNDERGOES A STARTLING TURNAROUND. BY THE 7th DAY OF WAR, THE PACT ADVANTAGE IN NUMBERS OF AIRCRAFT HAS BEEN ELIMINATED AND NATO GAINS THE ADVANTAGE AS TIME GOES ON.

(Cont'd)

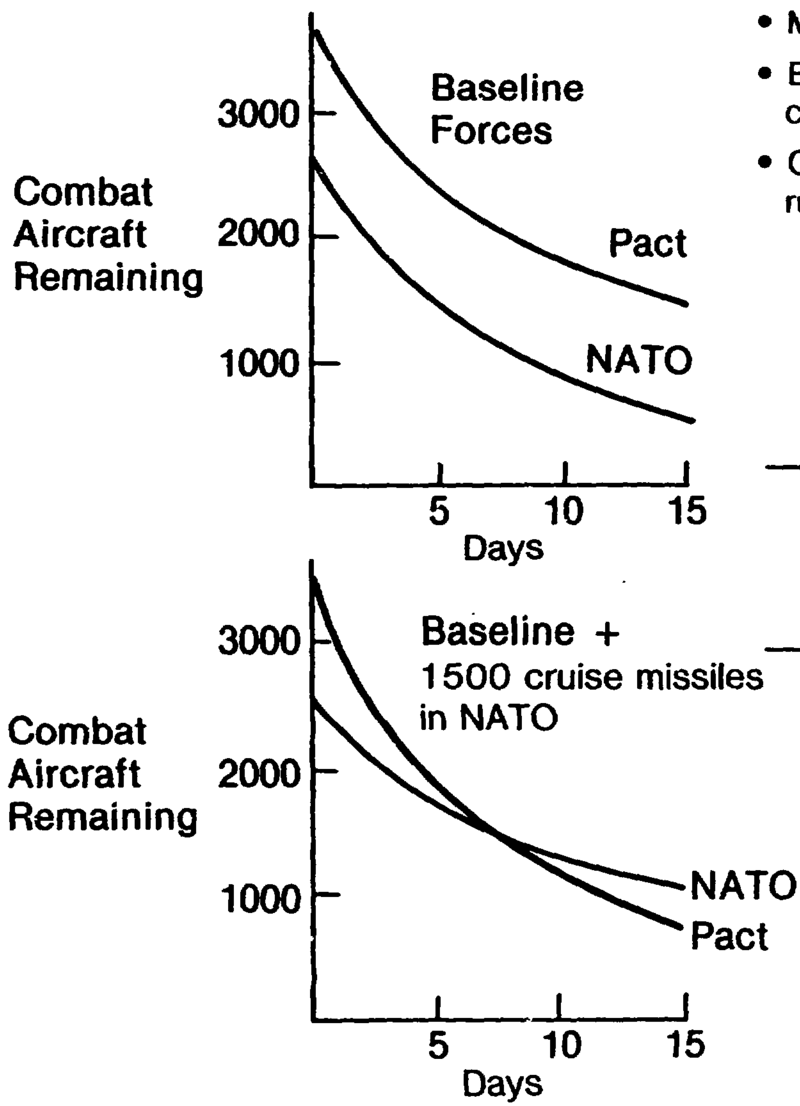
CONVENTIONAL CRUISE MISSILES - FORCE MULTIPLIER EFFECT
(Cont'd)

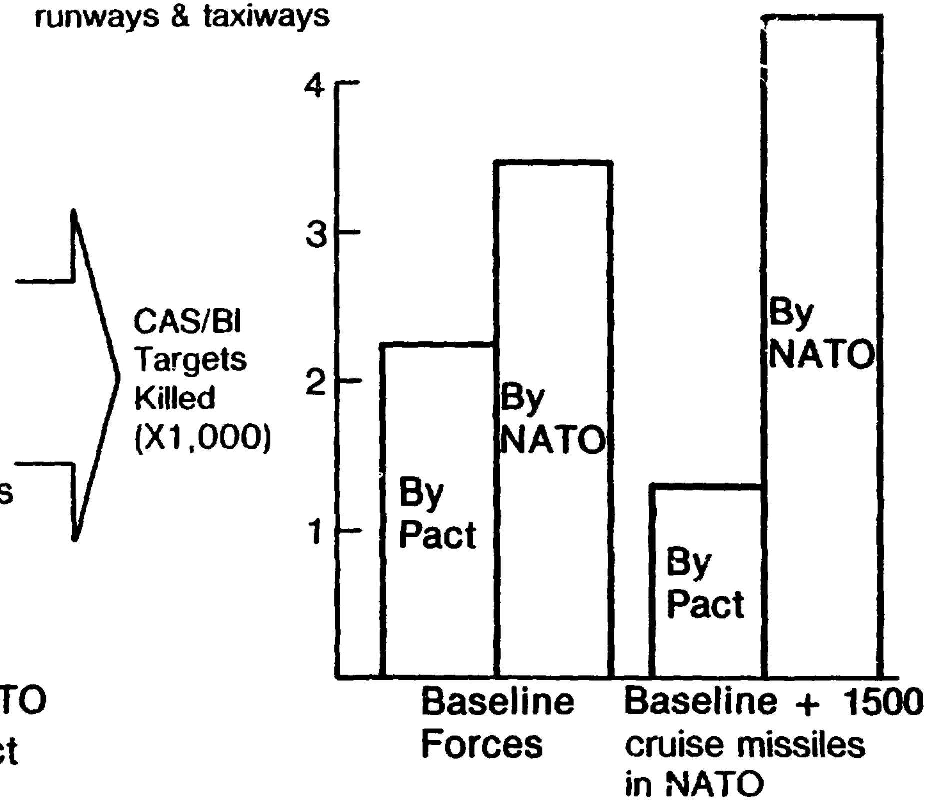
IN TERMS OF RELATIVE EFFECTIVENESS, MEASURED IN CLOSE AIR SUPPORT/BATTLEFIELD INTERDICTION TARGETS DESTROYED, NATO TARGET KILLS ARE INCREASED BY APPROXIMATELY 30% WHEN THE CRUISE MISSILES ARE ADDED, WHILE THOSE KILLED BY PACT AIRCRAFT ARE REDUCED BY 40%.

THE CONVENTIONAL CRUISE MISSILES BRING ABOUT THIS DRAMATIC TURNAROUND IN THE WAR THROUGH THEIR <u>FORCE MULTIPLIER EFFECT</u>. THE CRUISE MISSILES, BY CLOSING DOWN WARSAW PACT AIRFIELDS, REDUCE PACT AIRCRAFT SORTIE RATES WHICH, IN TURN, LOWERS NATO AIRCRAFT ATTRITION IN THE AIR AND ON THE GROUND, AND THUS INCREASES NATO AIRCRAFT SORTIE RATES AND OVERALL EFFECTIVENESS.

PRELIMINARY CAMPAIGN MODEL RESULTS

- Methodology: General Dynamics/Fort Worth campaign model
- Baseline forces: 1985 European scenario — cruise missiles
- Conventional cruise missiles applied only against runways & taxiways





23059278-11B

CONVENTIONAL CRUISE MISSILES FOR AIRFIELD ATTACK

WHILE IT IS HARD TO ACCURATELY CONVERT THESE EFFECTIVENESS RESULTS INTO A COST-EFFECTIVENESS STORY BECAUSE OF UNCERTAINTIES AS TO AIRCRAFT FORCE MIX AND COST ASSUMPTIONS, ONE CAN STILL GET A ROUGH IDEA FROM THE RESULTS OF THE COST EXCHANGE IMPACT OF INTRODUCING THE 1500 CONVENTIONAL CRUISE MISSILES. THE LIFE CYCLE COSTS OF THE 1500 CRUISE MISSILES PALE IN COMPARISON TO THE SAVINGS WHICH ARE REALIZED IN NATO AIRCRAFT. ONE CAN SEE THAT THE COST EXCHANGE RATIO, EVEN WITH CONSERVATIVE COST ASSUMPTIONS, IS VERY FAVORABLE TO NATO. THIS DATA, AGAIN, ONLY CONSIDERS THE USE OF CONVENTIONAL CRUISE MISSILES TO ATTACK PACT AIRFIELDS. THERE ARE OTHER MISSIONS, PARTICULARLY DEFENSE SUPPRESSION, WHERE THE POTENTIAL BENEFITS OF USING CONVENTIONAL CRUISE MISSILES APPEAR SUBSTANTIAL.

GENERAL DYNAMICS
Convair Division

CONVENTIONAL CRUISE MISSILES FOR AIRFIELD ATTACK

1985 European Scenario

COST

1,500 conventional airfield attack cruise missiles 10-year life-cycle cost (LCC) of
$750 - $1,500K each = $1 - $2B (—)

EFFECTIVENESS

Save 569 NATO aircraft with a replacement LCC of $15 - $30M each = $8 - $17B (+)

Kill 787 additional Warsaw Pact aircraft with a replacement LCC of $10 - $20M each = $8 - $16B (+)

Plus significant impact on ground war:
- NATO CAS/BI targets saved = 888 (+)
- Additional Pact CAS/BI targets killed = 1,000 (+)

Cost exchange ratio = From 8:1 to 33:1 in NATO's favor

23059433-08

CONVENTIONAL CRUISE MISSILES COMPLEMENT MANNED AIRCRAFT

THE RESULTS I'VE SHOWN, AS WELL AS OTHER STUDIES WE HAVE DONE AT CONVAIR, INDICATE THAT CONVENTIONAL CRUISE MISSILES COULD POTENTIALLY HAVE SUBSTANTIAL UTILITY IF EMPLOYED IN A COMPLEMENTARY ROLE WITH MANNED AIRCRAFT.

BOTH TYPES OF SYSTEMS HAVE UNIQUE STRENGTHS, MANY OF WHICH ARE SHOWN ON THIS CHART. FOR MANNED AIRCRAFT, THESE INCLUDE THEIR OVERALL FLEXIBILITY...EFFECTIVENESS AGAINST MOBILE TARGETS...AND COST EFFECTIVENESS FOR SUSTAINED OPERATIONS, THAT IS, CONFLICTS LASTING MORE THAN A FEW DAYS. FOR CONVENTIONAL CRUISE MISSILES, THE BENEFITS INCLUDE THEIR HIGH SURVIVABILITY IN LETHAL AIR DEFENSE ENVIRONMENTS, AND COST EFFECTIVENESS FOR THE GENERATION OF HIGH FIREPOWER RATES DURING THE EARLY DAYS OF A CONFLICT.

THE SYNERGISM BETWEEN THE CAPABILITIES OF THE TWO SYSTEMS COULD POTENTIALLY PROVIDE A SUBSTANTIAL INCREASE IN OVERALL FORCE EFFECTIVENESS, AT MUCH LOWER OVERALL COST THAN WOULD BE POSSIBLE WITH MANNED AIRCRAFT ALONE. CONVENTIONAL CRUISE MISSILES, PARTICULARLY IF USED FOR THE AIRFIELD ATTACK AND DEFENSE SUPPRESSION MISSIONS, COULD ENHANCE THE STRENGTHS OF MANNED AIRCRAFT AND HELP ACHIEVE AN OPTIMUM EMPLOYMENT OF OUR LIMITED AIRCRAFT RESOURCES.

CONVENTIONAL CRUISE MISSILES COMPLEMENT MANNED AIRCRAFT

Low Cost Aircraft

- Cost-effective sustained operations
- Effectiveness against mobile & dispersed targets
- Increased munitions payload for airfield destruction
- World-wide rapid reaction/deployment
- Manned flexibility
  - ✓ Multi-role
  - ✓ Threat reaction
  - ✓ Intel action
  - ✓ Real-time BDA
  - ✓ Targeting

Early IOC Conventional Cruise Missile

- Cost-effective surge operations
- Adverse weather, sustained runway suppression
- Adverse-weather effectiveness against EW/GCI, fixed SAMs, revetments
- High speed, low altitude, low signatures for high survivability
- Long range
- Low life-cycle cost

- Cruise missiles provide early surge capability & selective defense suppression
- Permit optimum employment of aircraft resources & cost-effective sustained operations

23059278-12A

UNMANNED BATTLEFIELD RECONNAISSANCE SYSTEMS FOR THE GERMAN ARMY

May 1979

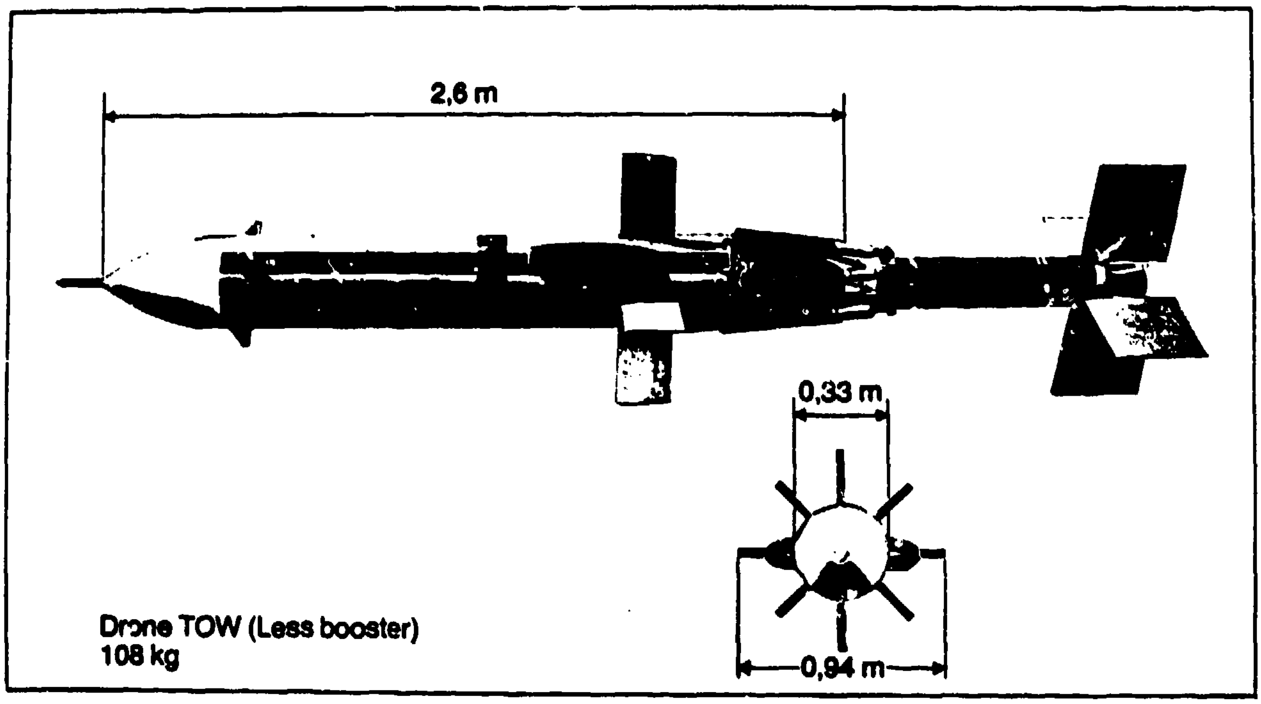
Dr. W. Klaar
Dornier

Unmanned Battlefield Reconnaissance Systems for the German Army

On January 31, 79 the German Army recorded its 1000th operational flight of the AN USD 501 reconnaissance drone system, better known under the name CL 89 (Figure 1). CL standing for Canadair, the developer and producer of the system. The 1000th operational flight with NATO had been recorded in December 78, where Royal Army [illegible]ations are included in the count. [illegible]rther procuremen[illegible] [illegible]cisions for the system have been made [illegible] Italy and recently by France.

It is obvious that unmanned vehicles for reconnaissance have made their way to the user and particularly the German Army has been pioneering this type of operation by not only continuously improving their equipment, training, and procedures but also by developing new systems like the airborne radar system ARGUS (together with France) and the AN USD 502 reconnaissance drone (CL 289, together with Canada). As this has been different at least in quantity and in decidedness from what most other armies do in this area, the questions raises: Why do they do it? and How do they do it?

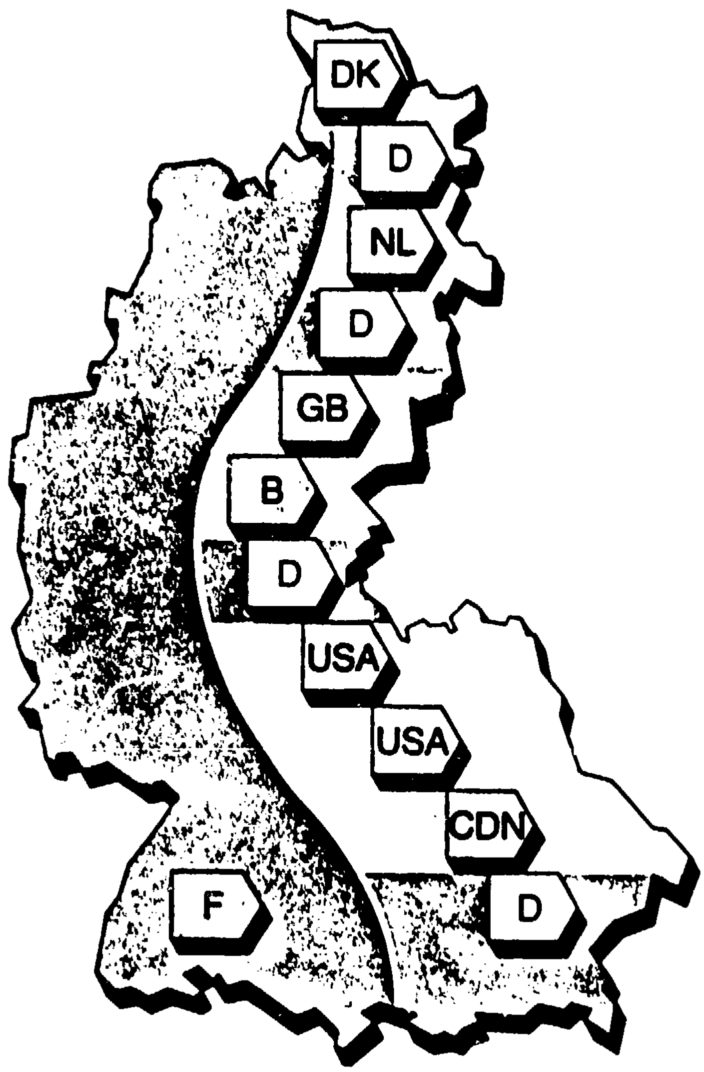
To answer the question why they do it, it is useful to realize the environment and situation of NATO groundforces in central Europe. The highest field command below headquarters in the German Army is the corps. We have three corps and they are deployed as shown in Figure 2. You find the German Corps shoulder to shoulder with Danish, Dutch, British, Belgian, US and Canadian Units. Each Corps commander has an area of responsibility about 80 to 100 km wide and 150 to 200 km deep. His area of interest on the other side of the FEBA is about the same size.



AN USD 501 (CL 89) Drone

DORNIER

Figure 1.



Deployment
of Allied Groundforces
in Germany.

DORNIER

Figure 2.

The majority of his targets will be mobile or transient with stationary periods typically 4 to 8 hours for command posts, artillery and air defense sites. The terrain varies from flat to hilly and mountenous with coverage as shown in Figure 3.

Forests plus villages, giving high protection are about 35 %, agricultural plus uncultivated land are about 60 %. Agricultural land includes orchards and hedges which again protect against detection.

Consequently line of sight conditions at 2 meters above ground are within 50 meters in 30 % of all cases and within 1500 meters in 83 % of all cases where terrain shape does not interfere with the line of sight. Obstacles are vegetation in 68 % and buildings in 32 % of all cases. These data have been developed for ground to ground targeting, but they also have implications for airborne standoff recce with its typically small ground grazing angles.

Besides, the EW environment is of high concern and WP forces are known for their capabilities of high power jamming of practically the whole EM spectrum and of keeping strict radio silence if required.

Consequently there is no doubt that airborne reconnaissance is necessary and there only remain a few options how to do it and how to organize it. Basic options are

- standoff or penetrating
- manned or unmanned
- Airforce or Army

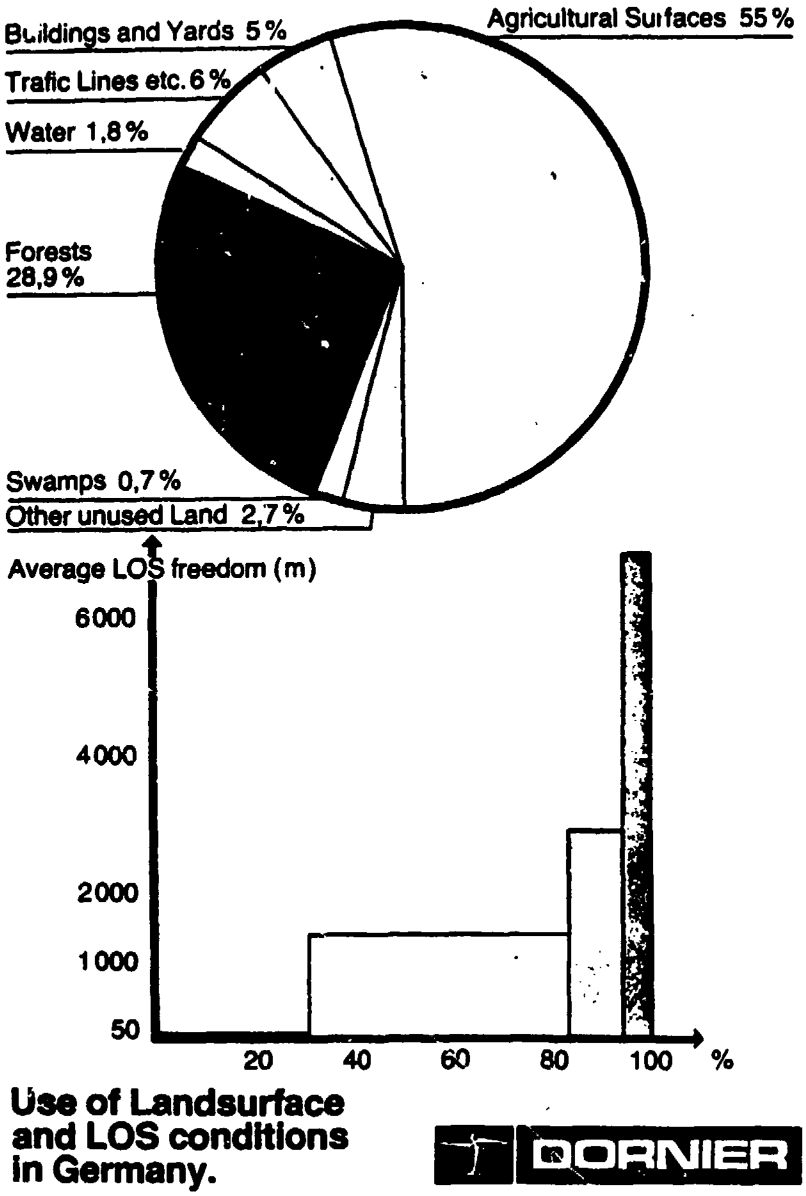

Buildings and Yards 5 %
Agricultural Surfaces 55 %
Trafic Lines etc. 6 %
Water 1,8 %
Forests 28,9 %
Swamps 0,7 %
Other unused Land 2,7 %
Average LOS freedom (m)
6000
4000
2000
1000
50
20
40
60
80
100
%
Use of Landsurface and LOS conditions in Germany.
DORNIER

Figure 3.

Discussing the reasons why the army puts so much effort into their own reconnaissance I have to mention the chain of command by which for example the army division commander has access to Airforce support (Figure 4).

Time elapsed between request and report is 6 to 8 hours minimum. Normally missions are requested for the following day. Number of recce missions available is less than required.

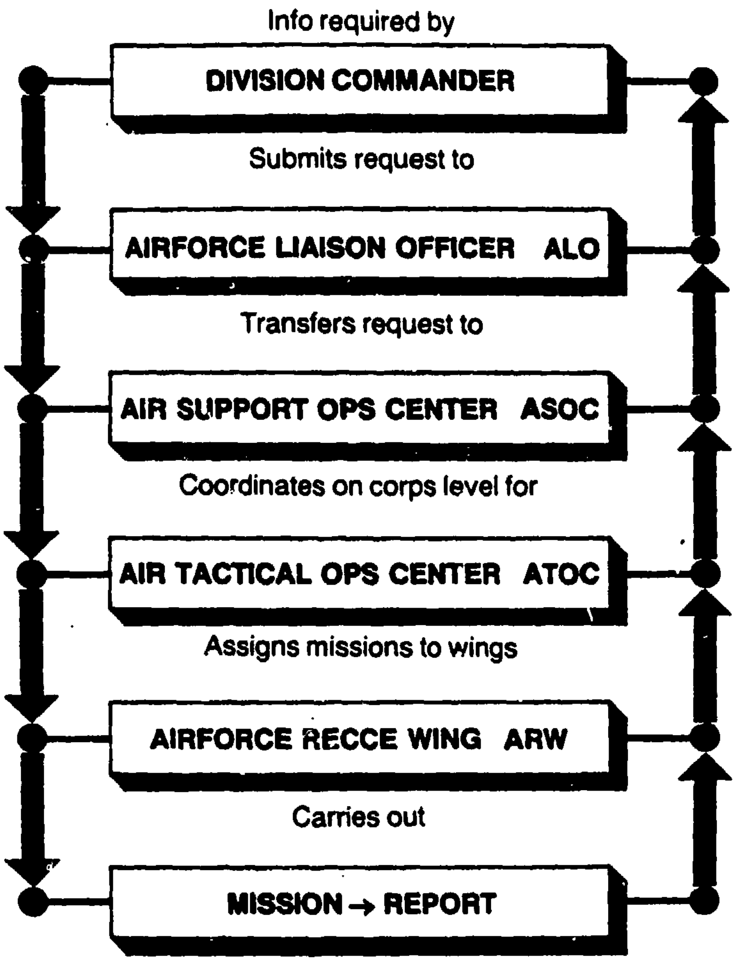
Now, as the army has a definite need for aerial reconnaissance and as this need can only partly be satisfied by airforce support, it was only a logical step to consider unmanned systems because these

- can be handled away from airfields
- need no pilots with respective skills and training
- are less susceptible to the airdefense threat.

The only remaining questions was, how would the army handle these systems under battlefield conditions. The answer of course is closely linked to the design and nature of these systems.

The AN USD 501 (CL 89) was first introduced in 1971. The system is part of the division's artillery regiment which has its own recce battalion, containing 4 different batteries. It is used for artillery targeting as well as for general reconnaissance.

The 108 kg takeoff weight drone has a cruciform wing and canard control configuration. It is powered by the Williams WR2-6 engine with 57 kg thrust, flying approx. mach 0,7 at sealevel. Total range is about 100 km, equivalent endurance is 8 minutes.



Chain of Command and Information for Airforce Battlefield Reconnaissance

DORNIER

Figure 4.

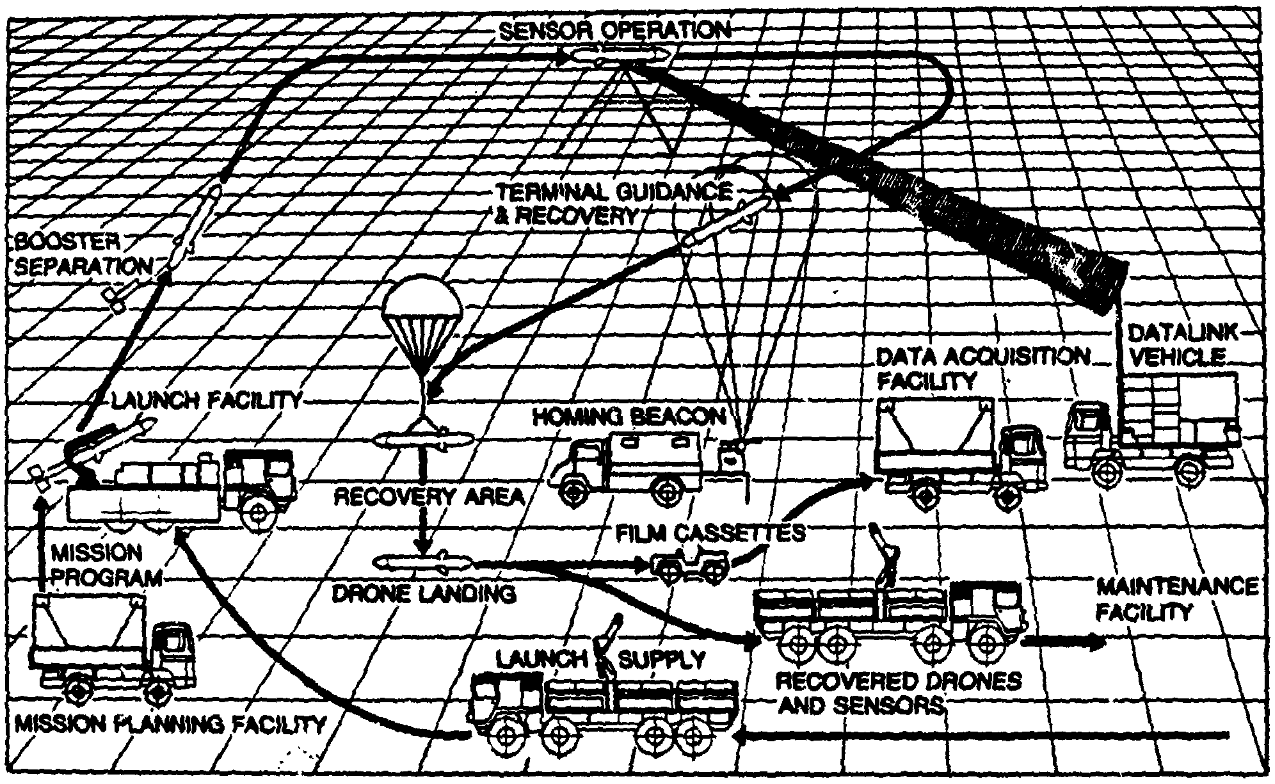
The drone carries a KRB 8/24 camera made by Zeiss, a three lens fan design, putting consequent rows of three frames on a single 10 inch film. The camera is motion compensated. Frame rows are taken with 60 % overlap for high resolution stereo evaluation. Alternative payload is the HSD 201 IR linescan, developed by Hawker Siddeley Dynamics, now British Aerospace (Figure 5).
The drone is booster launched, it flies completely preprogrammed, navigating by heading reference and airdata. For recovery it is picked up by a homing beacon and recovered by parachute + airbags with an accuracy of about 100 m.

CL 89 batteries which are considered one system consist of (Figure 6):

• 12 drones	
• about 50 ground vehicles,	including 2 launchers, level III maintenance gear, film development and evaluation facility, mission planning etc., making up a fully selfcontained fielded unit
• 100 soldiers	5 officers, 36 NCO's (10 in peacetime)

This battery moving into its site is ready for the first launch within 1 1/2 hours.

Responsetime between mission required and data available is 1 hour and will be 40 min with the automatic mission planning facility which is being introduced.



Mission Sequence

DORNIER

Figure 5.

Number of Drones	12
Number of Ground Vehicles	≈ 50
Number of Soldiers (5 Officers, 36 NCO's, 60 EM's)	≈ 100

Deployment Time to first Launch	1,5 h
Response Time	1 h → 40 min
Info Age	≈ 30 min

Number of Missions per Day	24 (1st day) 15 (following days)
Turn around time	≈ 3,5 h → 2 h
Man-hours field maintenance (l... ls 1 to 3)	≈ 3,5 h → 2 h
D...ne sortie life	10 to 40

CL 89 System Characteristics (Batter\)

DORNIER

Figure 6.

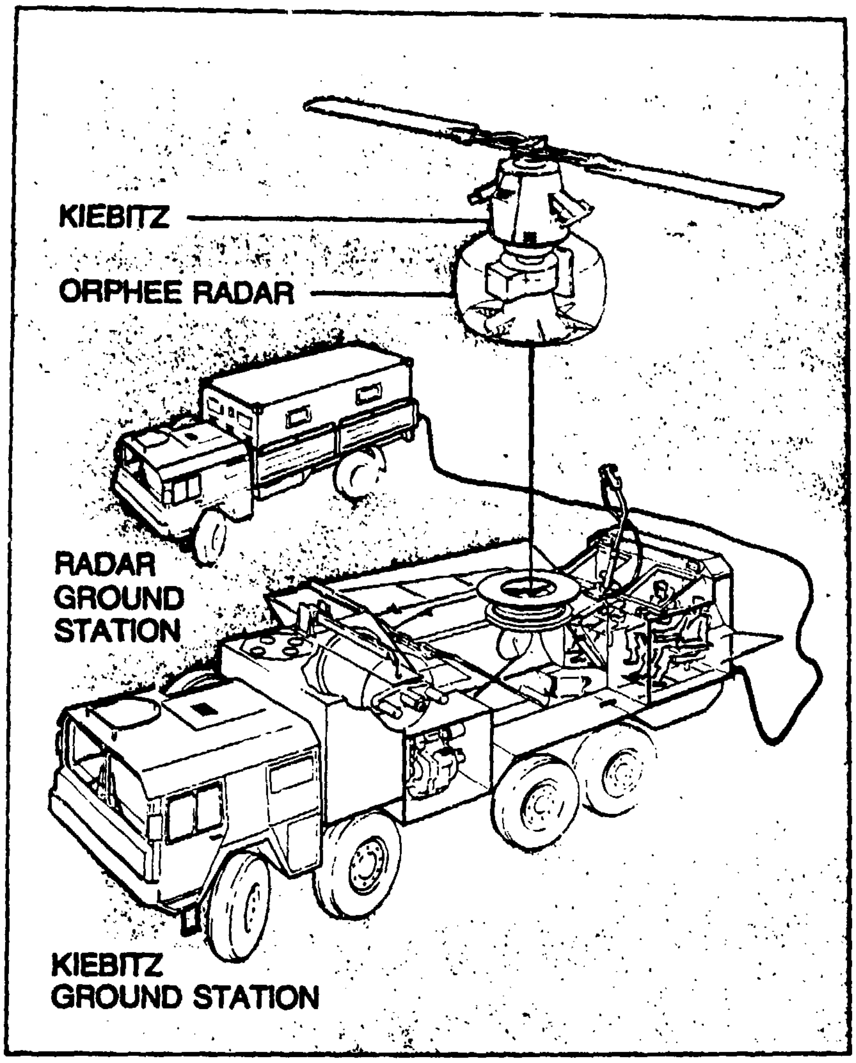
The system can fly 24 missions within the first days of a conflict, and 15 missions per day continuously. Turnaround time is 3 1/2 hours presently and will be 2 hours with the automatic check equipment which also is being introduced.

Present statistics show that man-hours of field-maintenance per mission are about 3 1/2 and will move to about 2 with automatic checkout. The required lifetime per drone is 10 missions. We have drones flying which have done more than 38 missions.

The CL 89 system, now fielded for about 8 years, of course has had its trouble periods in early times of its service life. But the efficient cooperation between the user, the German Army, our procurement organisation, the BWB, and industry have succeeded in overcoming these problems and resulted in a highly efficient operational drone reconnaissance system. With all humbleness, may own company, Dornier has contributed significantly to this success, as being in charge for industry maintenance and the post delivery services.

Consequently the German Army has built up sufficient positive experience and confidence to continue on this path of unmanned aerial reconnaissance.

For COMPLEMENTARY use together with CL 89 the ARGUS program was created (Figure 7). It comprises a little tethered helicopter platform which carries a battlefield surveillance radar. ARGUS is a joint French/German Program with France's LCT developing the ORPHEE radar and ourselves as main-contractors doing system integration and the KIEBITZ helicopter platform with its truckmounted groundstation.



ARGUS Battlefield
Surveillance System

DORNIER

Figure 7.

The platform carries 140 kg payload to an altitude of 300 m above ground. The tether cable provides for continuous fuel supply and for a safe data link. The helicopter rotor is driven by a standard Alison 250 C20 B turboshaft engine working on an aircompressor that feeds into the reactive drive nozzles which are on the rotorblade tips. The engine residual thrust is used for yaw control. This rather unique design sacrifices some fuel economy for vehicle simplicity. It provides an allweather system including deicing and 24 h/per day continuous on station capability.

ARGUS will again be deployed in the division's artillery reconnaissance battalion in near FEBA standoff missions.

The respective ARGUS battery will have three systems of platoon size with 2 exchangeable flight vehicles, one groundstation and one data evaluation vehicle each (Figure 8).

Personnel will be 18 with one officer, 5 NCO's and 12 EM's working in up to three shifts. The system is ready for operation 20 min after stop of the truck. Included are 3 min for climb of the platform. Move away time is similar. The radar will either be on station for 24 hours continuously or up to three flights/per system are required per day, with up to 24 hours total time. Field maintenance is again up to level 3. The required number of maintenance hours/ flight hour is below 5.

The system ARGUS and CL 89 are deployed within the same battalion and are linked to the same command and control system of the division's artillery regiment. This allows effective complementary use of the two systems in a variety of ways.

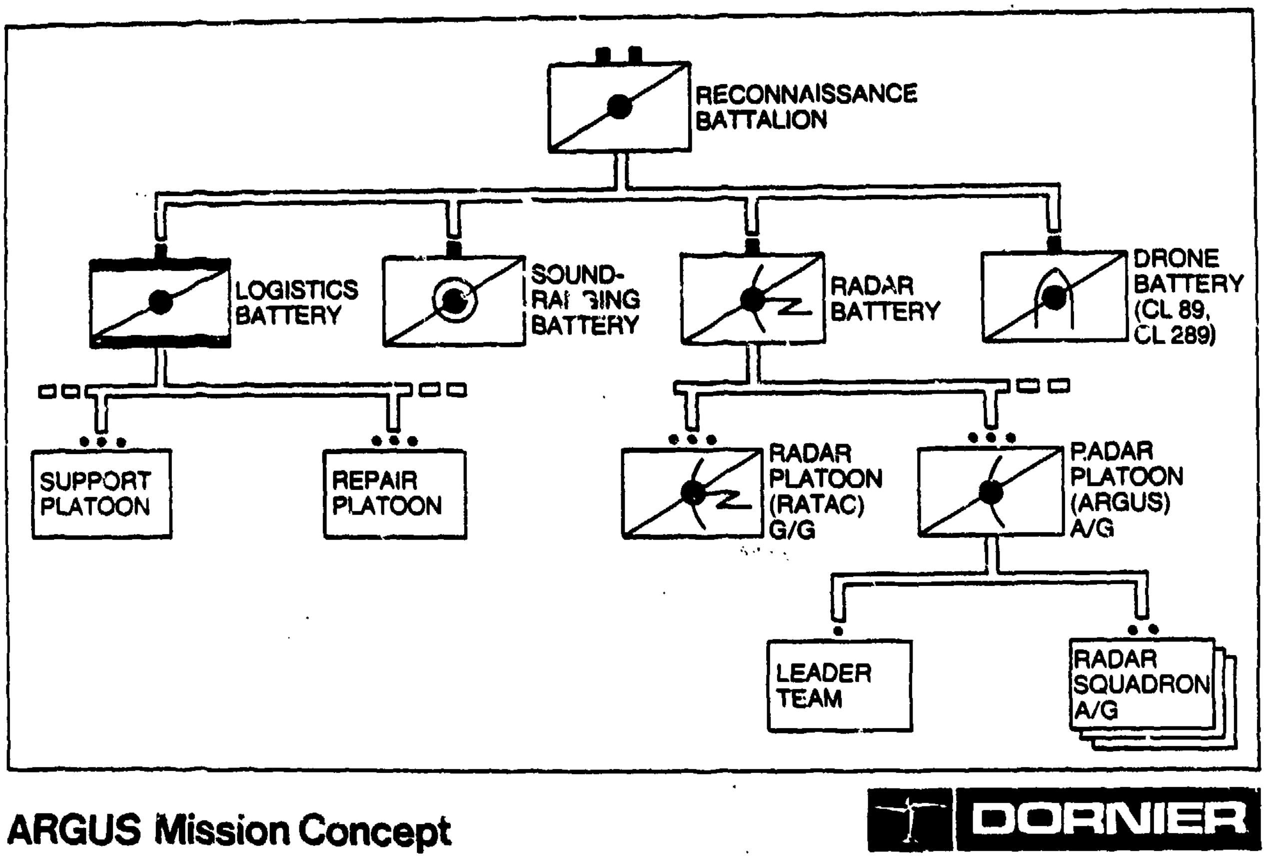
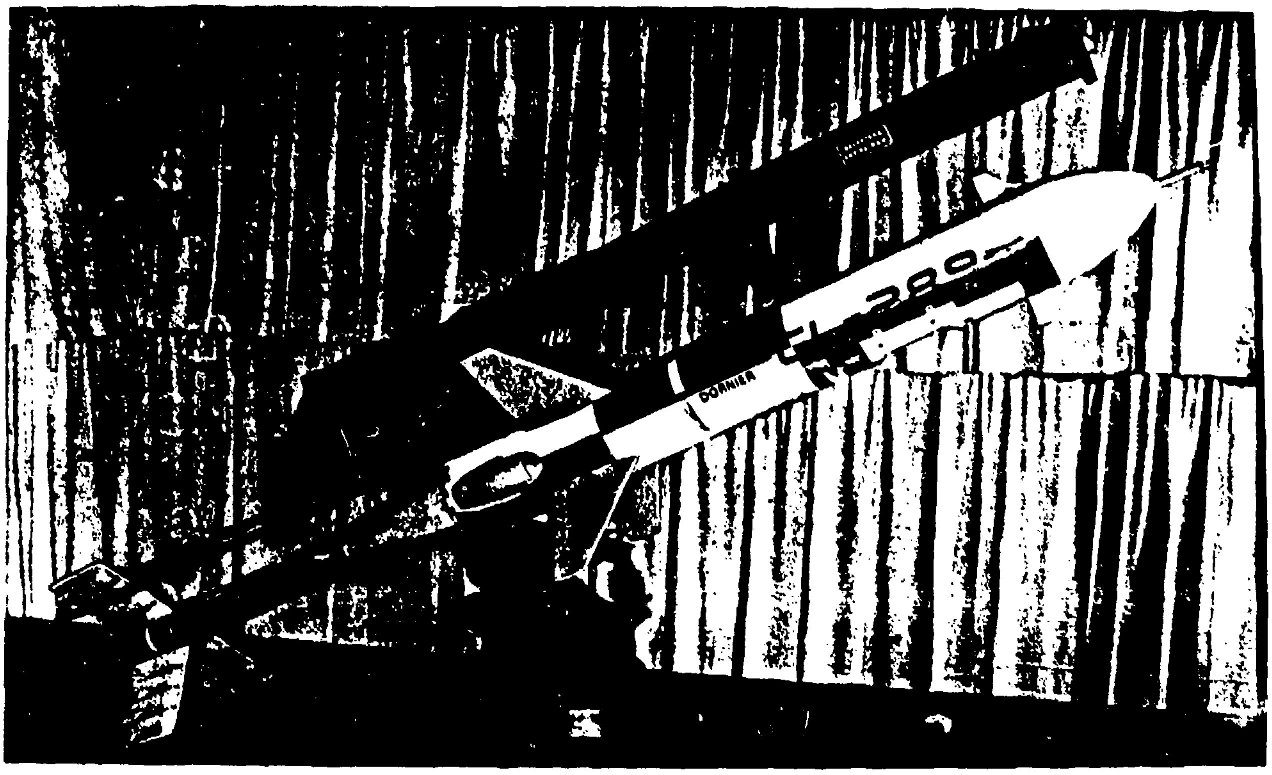

RECONNAISSANCE BATTALION
LOGISTICS BATTERY
SOUND-RANGING BATTERY
RADAR BATTERY
DRONE BATTERY (CL 89, CL 289)
SUPPORT PLATOON
REPAIR PLATOON
RADAR PLATOON (RATAC) G/G
RADAR PLATOON (ARGUS) A/G
LEADER TEAM
RADAR SQUADRON A/G
ARGUS Mission Concept
DORNIER

Figure 8.

- The drone can cover areas where the platform's view is shadowed.
- The drone can identify targets which the platform has detected through MTI radar.
- The platform can continuously track targets which the drone has detected or identified.
- The drone can operate when EW environment blocks radar operation.
- The platform can provide information, when the air-defense threat prohibits drone operation.

This type of combined operation will be feasible from about 1983 on.

At about the same time period the second generation of reconnaissance drones will enter service. The system is called AN USD 502 or CL 289 and it is designed for corps level (Figure 9). Development contractors are Canadair for the main contract and Dornier as co-contractor with a 50/50 worksharing between the companies. Drone configuration and system concept are rather similar to CL 89 with only a few major changes. Range is X times higher than for CL 89. Payload allows to carry a camera of the CL 89 type with extended film length together with a high resolution IR-linescan and a datalink package. The IR-System comprising sensor, datalink and receiver groundstation is being developed by the company SAT in Paris under contract of the French Government. Of course, the vehicle has to be bigger than CL 89.



AN USD 502 (CL 289) Drone DORNIER

Figure 9.

- Takeoff weight (without booster)
- Drone diameter
- Drone length (without booster)

Technilogical changes as compared to CL 89 have primarly been made in the navigation package, where we switched from airdata to a light weight doppler system from Canadian Marconi and to a central digital computer which we are making at Dornier.

This was necessary to achieve proper accuracy for the higher range and it also results in further cutting down maintenance hours at a factor of about 2, compared to today's CL 89. So we will have 4 to 5 maintenance hours per flight hour of the drone. CL 289 will be powered by a new engine, the 100 kg thrust turbojet KHD T 117. The first of 10 prototypes has been completed. Flighttests will start before the end of 79.

CL 89, CL 289 and ARGUS together constitute a triade that covers the reconnaissance needs of the corps and divisional levels (Figure 10). For brigade level our army is working on solutions which may end up very close to the US army's TADARS or to the UK's MRUASTAS. We are prepared for both ways.

In addition for scout missions on battalion level or below this little inertially driven platform is proposed. Our prototype has demonstrated endurance of about 1 minute with an instant camera, that takes pictures from 50 or 100 meters altitude.

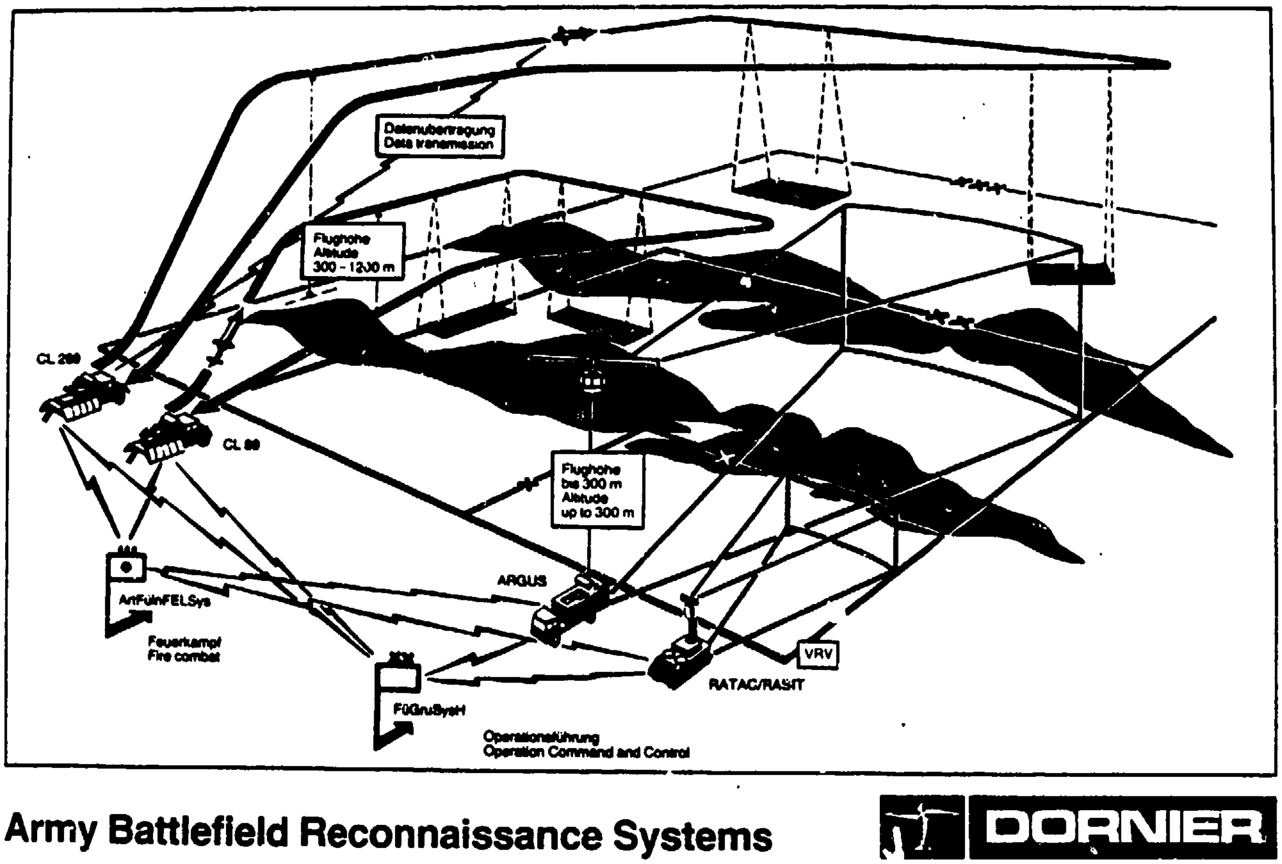

Datenubertragung
Data transmission
Flughohe
Altitude
300 - 1200 m
Flughohe
bis 300 m
Altitude
up to 300 m
ARGUS
ArtFuInFELSys
Feuerkampf
Fire combat
FüGruSysH
Operationsführung
Operation Command and Control
RATAC/RASIT
VRV
Army Battlefield Reconnaissance Systems
DORNIER

Figure 10.

Remains to summarize that the battlefield reconnaissance problem lends itself particularly to unmanned solutions. The unmanned airborne reconnaissance system offers to the army commander a degree of operational flexibility and responsiveness which can hardly be matched by airforce support alternatives. The operational load, which these systems imply have become acceptable through proper design features and deployment modes. Operational experience of the German Army with the CL 89 system has created sufficient confidence in this technology and thus convinced us to further continue this way. We expect that US army operational experience with their new TADARS system will be similarly positive. I would like to encourage Navies and Airforces of our countries to observe these projects as closely as possible, to share the experience and to expand their application of unmanned vehicle technology into increasingly intelligent systems.

May 1979
Dr. Klaar

Klaar

ASSOCIATION

FOR

UNMANNED VEHICLE SYSTEMS

San Diego, California

May 29 - June 1, 1979

AUTOMATED GUIDANCE FOR GROUND VEHICLES

Boris Dobrotin

Jet Propulsion Laboratory

California Institute of Technology

AUTOMATED GUIDANCE FOR GROUND VEHICLES

Boris Dobrotin
Member of the Technical Staff
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

SUMMARY

The Jet Propulsion Laboratory (JPL) has developed two different types of autonomous ground vehicles: a high speed, maneuverable wire following tank target and an obstacle avoiding planetary rover. The first represents a vehicle dynamics problem, while the latter type is primarily a vehicle kinematics problem. Breadboard vehicles were built to obtain experimental results and validate the designs. Both vehicles met their design goals.

During the test phases, it became apparent that ground vehicles need remote sensing in order to achieve the full benefit of on-board autonomous guidance. This is a function normally supplied by a human operator through vision. For the high speed vehicle, remote sensing through vision allows the equivalent of increased system lead. In the case of the rover, remote environmental sensing is the initial step in path planning and allows pre-programmed maneuvers for obstacle avoidance.

A laboratory model of a real time vision sensor has been built and is operating in the JPL Robotics Research Laboratory. A parallel effort at the California Institute of Technology has developed an implementation of a flight-type sensor using Very Large Scale Integration (VLSI) to build a pipeline processor. Using the techniques of VLSI and pipeline processing, it is possible to build a small rugged vision sensor which can be used as a remote sensor in both high speed servo systems and real time path planning algorithms.

This paper discusses the operating characteristics of the two classes of vehicles, presents the vision sensor configuration and development status and discusses the application of remote sensing to autonomous vehicle guidance. The development of a vision sensor is recommended.

VEHICLE CHARACTERISTICS AND REQUIREMENTS

This section discusses the development of the two classes of vehicles. Their differing applications and design goals are presented together with experimental results. The existing operational capabilities and future requirements are outlined.

High Speed Maneuverability

The target vehicle was developed under the auspices of the U.S. Army Armor and Engineer Board, Ft. Knox, Ky., with the intended use of tank evaluation. The concept was to build a vehicle which would simulate the maneuvers of an opposing tank and stress the fire control system by using high lateral accelerations (> 0.5 g.) and straight line velocity (> 50 mph.) In order to increase the realistic effects of the target, the target was not to be artificially protected (by earth embankments, for example) and the tank under evaluation was to be allowed to use live fire on the target.

The research described in this paper was carried out at the Jet Propulsion Laboratory, California Institute of Technology, and was sponsored by the Department of Defense through an agreement with NASA.

The chassis and powerplant were constructed by the U.S. Army Armor and Engineer Board with the goal of combining high manueverability and low cost (the target lifetime was estimated to be 10 rounds). With this goal surplus components were selected: the chassis was an AMC M175 1-1/4 ton truck and the power plant was a Ford V8 engine and transmission. The primary modifications consisted of removing the body, transmission, and front wheel drive and installing the V8 engine and transfer case. Wide tires were added to improve surface cohesion. This modified vehicle is shown in Fig. 1. A separate contractor (Wood Ivy, Inc.) installed the electronic logic, including the speed control, and initially modified the chassis for remote control.

The objective of JPL's development program was to design, build and test a guidance system based on wire following concepts, which would meet the target vehicle's performance specifications. These primarily consisted of reproducing a tanks attack maneuvers and two were selected as typical: a high speed straight line dash and lateral sinusoid maneuvers. These two maneuvers provided the two basic design parameters: straight line stability was required up to 50 mph and lateral acceleration was to reach 0.5 g at 25 mph (or 1/2 of the maximum cohesion limited lateral acceleration available, whichever was less). The operational surface was crushed rock, with a coefficient of friction estimated between 0.7-0.9.

Control System

The wire guidance system selected was based on previous experience both at JPL and elsewhere (Refs. 1, 2, 3). However the application of wire guidance to a maneuverable vehicle represents a much more complex problem. The references basically describe transportation systems, which have extremely regular motions and limit lateral accelerations to 0.05 g, an order of magnitude less than the target vehicle. The guide wire is installed with the aid of surveying instruments, providing an exact course. The manually installed target vehicle course, as discussed below, did not provide an exact course. Indeed, lateral deviations presented in Ref. 2 never exceeded 0.5 in., while lateral deviations of ± 3 ft were acceptable for the target.

Figure 2 shows the vehicle kinematics while Figure 3 is the basic block diagram. A wire energized with an AC voltage provides a lateral reference signal for antennas mounted on the front and rear of the vehicle. This reference signal is processed to provide a control signal for a hydraulic steering servo loop. The steering feeds back position to the antennae through the vehicle dynamics and kinematics.

A detailed block diagram is shown in Fig. 4 (from Ref. 4, which contains a detailed linear analysis of the vehicle control dynamics and response.) The antennas measure lateral displacement in discrete steps over a range of ± 3 ft. The guidance system which develops the steering servo error signal uses the lateral position error (E) and the heading angle error (ψ) as well as velocity. The position error is integrated [KI/S] to provide a constant steering angle (δ) with a constant turn (curve) with zero offset. The position error gain (K_E) and the loop gain (K_C) are both divided by vehicle longitudinal velocity (V) in order to provide lower gain at higher speeds.

The steering servo loop uses a hydraulic servo valve controlling a double acting cylinder attached directly to the steering linkage. Feedback is through a potientometer measuring the tie rod displacement. Hydraulic pressure is supplied through a standard automotive power steering pump and system pressure is set through an external relief valve.

System gains were selected to optimize steering response while still maintaining adequate stability. This gain selection was done in two stages: linear response through simulation and analysis, and experimental results. Both the analytical and experimental gain agreed within 10%.

The analytical results included the effects of the transition from a straight line (radius $= \infty$) to a curved segment (radius = constant, K) and provide a gradually changing radius (i.e., spiral, $\infty > r > K$). The actual wire course, laid out on a dry lake bed at Edwards AFB, Rosamond, Calif. was intended to duplicate an operational course and was laid out manually. Straight lines were sighted in visually, and curves were marked with a rope compass and then approximated with straight line segments. This radius of curvature varied between ∞ and zero at the connecting points of the straight segments. A course which includes the required maneuvers was used and is shown in Figure 5.

Operational Characteristics

Satisfactory performance was obtained. That is, the vehicle remained controllable at straight line speeds of 50 mph as well as lateral accelerations which reached the limitation imposed by 1/2 the available coefficient of friction. The vehicle remained within ± 3 ft of the reference wire.

The analytical effort provided a linear approximation to a very non-linear system, with very good results. As mentioned above, predictions of system and loop gains were within 10%. While the gross performance (i.e., the maximum bounds) was predicted by the linear analysis, the actual response of the vehicle was perturbed by the non-linear elements. Instrumentation data consisted of strip chart recordings and photographic records (Ref. 5), which provided only approximate performance results.

It appears that the primary reason for correlation between the analysis and the experimental results was due to the vehicle inertia and steering response. That is, the vehicle could not respond to the measurement non-linearities, but instead established a 1 Hz limit cycle (the expected natural frequency) as a result of these non-linearities but curve tracking proved to be a problem. On a constant radius curve as described previously, the change of direction between line segments represents a large step input into the steering servo, and actually creates peak lateral accelerations much higher than the average acceleration. During the sinusoid lateral acceleration phase, peak acceleration was limited by the effect of the integration. While the integrator was needed to maintain a constant steering angle (ψ) with minimal offset, it also required a small amount of time to null the offset integral when the direction (i.e. left to right) of the curve was reversed and a change in ψ was needed. In other words, the vehicle would overshoot the curve reversal until the integrator "caught up".

Though performance met the requirements and operation was satisfactory, the vehicle's maneuvering capability was still below that which could be provided by human manual control. Even though the steering response was several times faster than that of a human's (a human's response is $\sim$1/2 Hz, the vehicle steering servo response was > 2 Hz), the vehicle capabilities were less than a human's. The problem is one of sensing. The vehicle sensors represent the equivalent of a human constrained to look downward at the front bumper, while the normal human characteristic is to look forward from between 50' to 200', so that steering response may be initiated prior the course's actual changes. This human feature is possible through remote sensing (i.e., vision) and is the equivalent of lead in an automatic servo system. The effects of increasing the antenna lead distance are discussed in Ref. 4 where hypothetical antennas were assumed 25' and 10' in front of the vehicle's axis. Much higher lateral accelerations were theoretically possible, confirming the assumptions presented above.

Obstacle Avoidance

In addition to the highly maneuverable vehicle described above, JPL developed a vehicle capable of obstacle avoidance, i.e., one that can select a path through a group of rocks, craters, etc. Intended for planetary surface exploration, this

vehicle presents quite a different problem. Instead of assuming a predefined course, and controlling the vehicle dynamics to maintain that path, the planetary rover must define its own path and the path maintenance problem is one of the vehicle's kinematics.

This path finding vehicle (or rover) is intended for exploration in terrain whose detail is unknown, though the gross surface features are established prior to the rover's trip, through orbiting satellites. Features on the order of hundreds of meters are known, but small obstacles which would impede the rover's progress are unknown. The mode of operation is for a (remote) human viewer to select the vehicle's goal in the vehicle's co-ordinate system, and the vehicle finds and maintains the best path to it. This path determination may be done either incrementally or at the start of the traverse. The rover then maintains its position with respect to the target and steers to maintain the "best" path.

As a specific example, Ref. 6 describes the design of a Mars planetary rover which would have a range of 100 km in two Earth years. Vehicle autonomy was necessary since the round trip communication light time between Mars and Earth (which ranges from 8 min to 30 min) would prevent direct Earth control of the rover. This vehicle used tracks instead of wheels, and with 200 watts of power was capable of 1.5 meter/min. This proved to be satisfactory for scientific research.

In order to assure satisfactory path selection and maintenance, both a scanning laser rangefinder and stereo television cameras were included in the design as vehicle guidance sensors (these also would be used for scientific purposes). Operation of the sensors, path planning computations and obstacle avoidance algorithms would be sequential. Range and contrast data would be obtained from the sensors, a computer would process these data and select a short range path. The vehicle would move, and the sequential procedure repeated. Ref. 6 developed a timeline for such a path selection technique and it demonstrated that the process would be a very tedious and limiting technique, although satisfactory for the proposed mission.

Further work, presented in Ref. 7 demonstrated that it was possible to guide a rover continuously by processing video data in real time and and to remotely determine the location of obstacles detected prior to start of motion. This technique was successfully demonstrated using the JPL Laboratory rover and a general purpose digital computer for both vision data processing and vehicle guidance. This rover is shown in Fig. 6.

Though the demonstration clearly established the validity of real time vision control of a vehicle's path, again the rover's performance was limited due to the computational capabilities available. While three obstacles could be tracked at one time, obstacle identification was possible only prior to the start of the traverse. Ref. 8 proposes a solution based on a JPL distributed computer network. In this system, the data were processed in one computer dedicated to the TV camera, the relevant information extracted and passed on to an object identification and path planning computer. While such a computer network is necessary to provide the various guidance functions for a rover, the large volume of data produced by a TV sensor requires some type of preprocessing prior to transfer to a general purpose computer for high level processing. Thus, requirements are again established for a real time flight type vision sensor.

VISION SENSOR DEVELOPMENT

Vision sensing, for the purposes of this paper, is defined as obtaining control parameters from remote sensing of the environment through the use of television data. This definition is much narrower than the traditional definition of vision. However this narrower definition is suitable for the remote sensing required for vehicle control and establishes practical bounds for the problem.

Initially, work in the vision sensing field was termed "scene analysis" and was aimed at computer reproduction of a human's visual image understanding. In scene analysis, efforts were made to identify each object in the field of view, describe its relationship to the overall scene, and essentially draw the same conclusions a human would. This approach to vision sensing requires a large general purpose digital computer, complex algorithms, and takes a long time (as much as 8 hrs per picture). While work is progressing in the general scene analysis field, some of the simpler, existing techniques may be applied to practical problems.

Work in JPL's Robotic Research Program has gradually evolved from scene analysis into developing vision sensing techniques which are simple, fast, and only produce the needed information (a local view, as opposed to a global view). Instead of reproducing a human's complete vision process, the JPL effort has been aimed at satisfying a machine's much more limited needs with a subset of human capabilities. Rather than identifying all the objects in a scene, the a priori knowledge of the machine's operation is used to locate and measure only the parameters needed. The object is to simplify the problem as much as possible to minimize the data processing needed.

Simple fast methods of image processing are intertwined with the development of specialized, high speed digital processing devices: micro-computers, IC based analog-to-digital converters, IC memories, solid state cameras, etc. Thus, not only are the general processing algorithms available, but the hardware to implement these techniques is also available. The concept has changed from supplying raw TV data to a large general purpose computer for scene analysis and waiting for the final output to preprocessing with specialized hardware and using a micro-computer to perform the final, high level information extraction.

The present state-of-the-art is represented by the sensor system described in Ref. 9. This sensor, now operating in the JPL Robotics Laboratory, supplies object edge boundries in real time, while automatically adjusting the TV camera's iris and focus controls. The output data then encoded for easy transfer to and processing by a higher level computer to do object identification and tracking. The input to output data reduction is three orders of magnitude, allowing the higher level information to be easily extracted.

Fig. 7 shows the sensor configuration. Essentially it represents a three stage pipeline processor with a microprocessor supplying feedback control to the processing and interfacing with the higher level computer (host). The sensor is implemented in transistor to transistor (TTL) logic using bipolar memories, solid state cameras with commercial lenses, and a commercial microprocessor. It provides an edge map at commercial TV frame rates (30 fps) and a resolution of ~200 x 200 pixels. It is possible to increase the processing speed by a factor of two which, with the existing timing margin, allows camera resolutions of 512 x 512 pixels. The use of two cameras, as shown in Fig. 7 allows stereo measurements.

In order to produce an operational vision sensor, a decrease in size and an increase in operational speed is needed. These requirements can be met through the use of VLSI technology. A functional design of a VLSI sensor is described in Ref. 10. The pipeline processor can be reduced to a total of seven chips including the sensing element. Optics and the microcomputer capability would be dictated by the specific application. Such a design represents the next evolutionary step in vision processing sensors, and permits field application of this capability.

APPLICATIONS

The vision sensor configuration described above represents a general purpose capability which may be applied to a wide spectrum of control problems

where remote sensing is important, either for position information or for environmental characteristics. Thus, this sensor development represents enabling technology for automation of a wide variety of low level control functions now performed by humans. It should be mentioned that for some tasks where the sensor can remain stationary (i.e., factory piece part inspection), remote sensing through vision data processing is already in use. The issue addressed in this paper is the development of a "flight type" sensor which is light enough, rugged enough, etc., to be used on operational vehicles.

Two control problems have been previously identified. One problem is visual line tracking to control a vehicle's path. The other includes object identification and location, so that a path may be selected. Application of remote sensing to both problems remove severe constraints from the problem solutions available and extend the capabilities of the vehicle. Both applications represent control functions easily performed by humans, but extremely hard to duplicate via machines. Yet, if these two basic functions of path selection and path maintenance were automated, a large variety of detail applications can be envisioned: vehicle entry into hazardous areas (fires, bomb disposal, etc.), vehicle safety (automatic traffic headway control), remote operations (mining, orbital docking).

Development of a vision sensor which could track a continuous line (or even a discontinuous line, such as lane markers) would increase the speed and maneuverability of a vehicle by providing advance information on the path direction (i.e., control system lead). A human controls a vehicle by using advance information about the path: how long is the straight segment, is the curve left or right, and how sharp? In addition, the human only uses relative accuracy: how far am I from the tree, how wide is the path? There is no "exact" path as represented by a wire; a human's path is dictated by boundries which are always wider than the vehicle. Thus, constraints imposed on wire following vehicle control do not represent the best possible approach for vehicle lateral control, but rather are constraints imposed by the path/sensor configuration.

The wire defines the course and the sensor measures the vehicle's deviation from that course. These are obvious statements, but imply a multitude of not-so obvious constraints. In an operational situation, it is extremely difficult to lay the wire precisely, and over open terrain the wire does not form exactly straight lines, nor does it form perfect curve transitions or even curves. Antenna width is constrained by the number of antenna elements one can mechanize and vehicle width. High response is needed to follow changing curve radii due to lack of advance information, but this leads to control plant instability.

Contrasting the wire following constraints with a human's driving technique, it is obvious that a human's visual data allows effective control of the vehicle dynamics with a much lower control bandwidth. The simple addition of a forward looking line tracking sensor adds this capability to an automated vehicle.

The obstacle avoidance task is much more complex, but a solution is required for truly autonomous operation. A vision sensor of the type described does not lead directly to the problem solution, but the sensor does provide mandatory basic instrumentation. Several efforts (Refs. 11, 12 for example) have been made to develop and test myopic or blind rovers. The results have been satisfactory in simple environments, but the missing vision capability has prevented these rovers from operating in an extensive natural environment. The JPL rover has shown that it is possible to control a rover using simple vision data processing, allowing real time vision data to be developed and used on board a rover.

CONCLUSIONS

The two general classes of vehicle control (lateral direction control, and obstacle avoidance) presented in this paper are greatly limited by lack of a vision

sensing capability. The use of vision would allow entirely different modes of operation, more closely approximating that of a human. In conjunction with the need for vision in automating these tasks, a vision sensor system has been developed which is capable of being extended into an operational unit. This coincidence of need and capability is fortunate and should lead to more autonomy in ground vehicles.

Once these two immediate problems have been solved, a whole host of related problems can be automated. Automated control of urban vehicles is of interest to the Department of Transportation. NASA can use a vision sensor for automatic spacecraft retrieval from Earth orbit, as well as automatic rendezvous and docking in planetary orbits. The Department of Defense is presently interested in remotely piloted vehicles which require a high bandwidth communication system to supply TV data to a ground based pilot. A vision sensor would permit the control loop to be closed on-board the craft, and visual data supplied to the human operators by low bandwidth TV.

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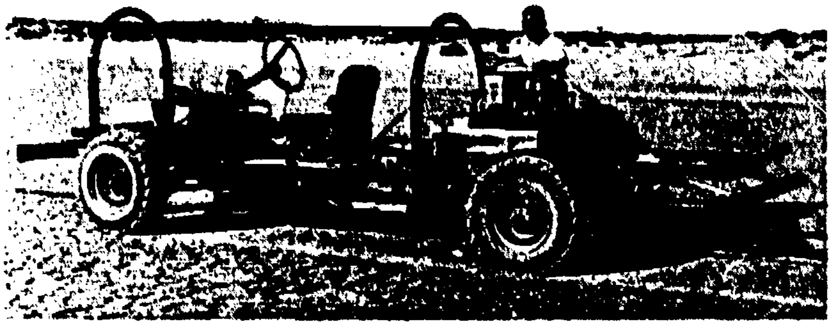

FIGURE 1. JPL HIGH SPEED WIRE FOLLOWING VEHICLE

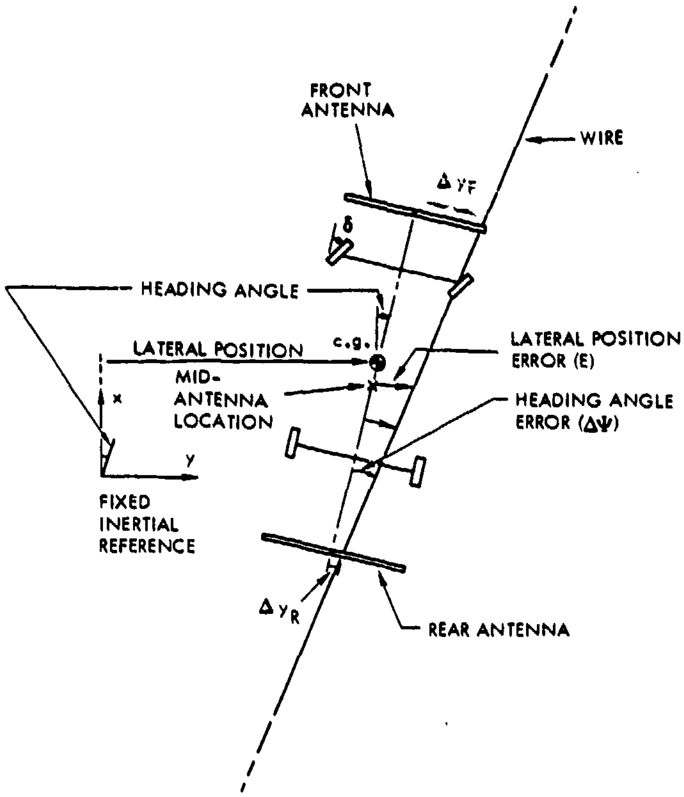

FIGURE 2. WIRE/VEHICLE KINEMATICS

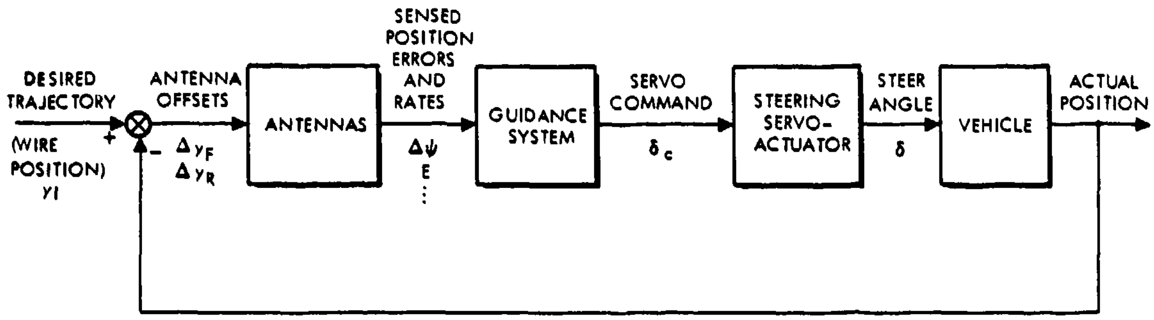

FIGURE 3. SIMPLIFIED BLOCK DIAGRAM OF ARMY/JPL WIRE FOLLOWING VEHICLE

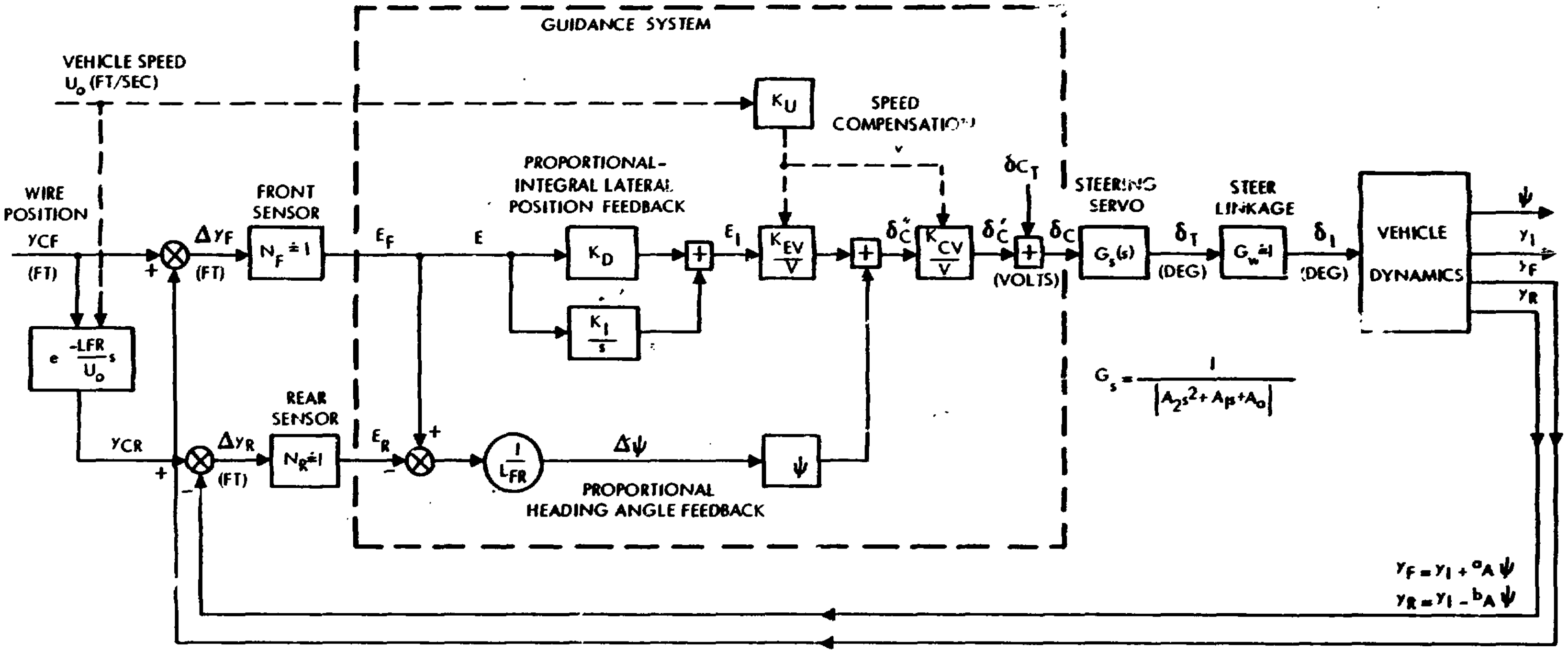

FIGURE 4. GUIDANCE SYSTEM DETAILED BLOCK DIAGRAM

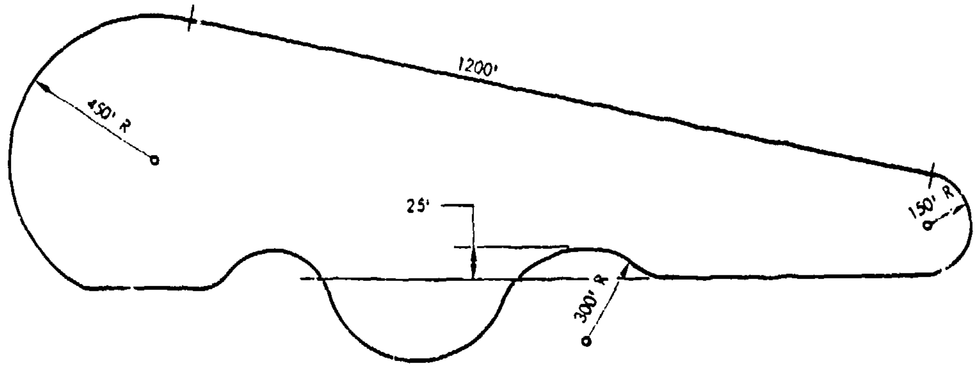

FIGURE 5. TARGET VALIDATION COURSE

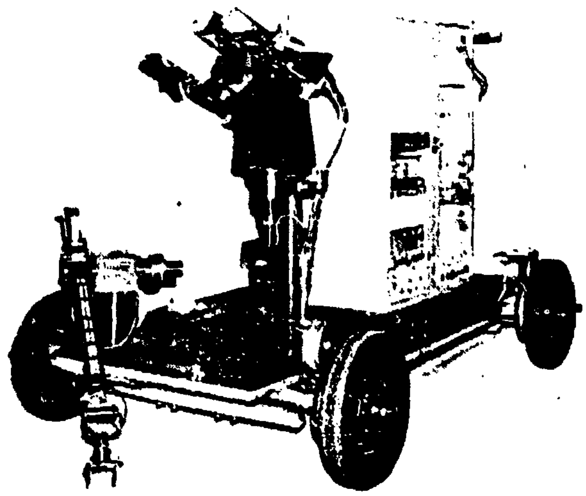

FIGURE 6. JPL LABORATORY ROVER

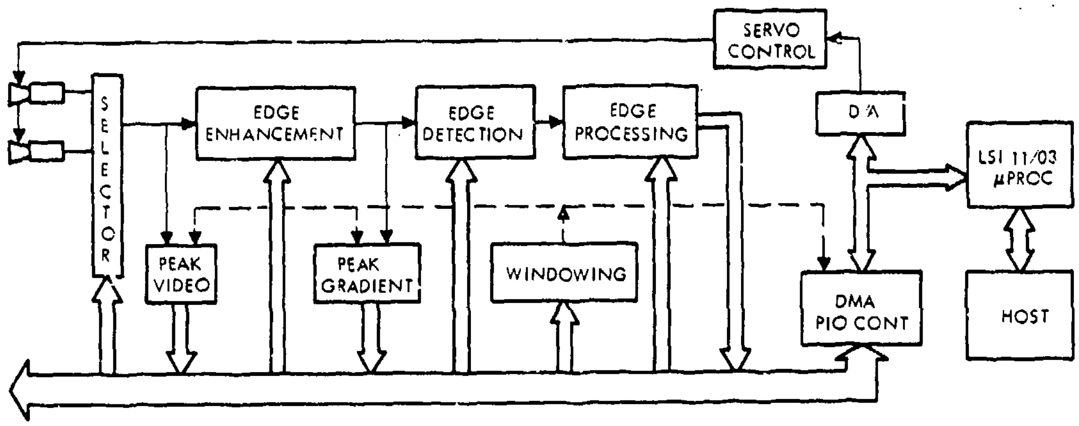

FIGURE 7. JPL VISION SENSOR CONFIGURATION

CRUISE MISSILE AIR LAUNCH IN THE
OPERATIONAL ENVIRONMENT

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ABSTRACT

The jettison and launch envelope for the Air Force air-launched cruise missile encompasses a broad range of altitude, mach number, and atmospheric conditions. Mission considerations require safe jettison of inert missiles and cruise missile launch at rapid intervals. The close-in flow fields of the B-52 carrier aircraft are complex and varied because of the possible stores configurations at launch. The off-nominal launch conditions magnify the number of conditions that may be critical for the design of the missile and launch equipment.

Requirements for cruise missile air launch are examined and critical launch and jettison conditions are identified. Wind tunnel test results are presented illustrating rapid aerodynamic force variation with stores location, attitude, and distance from the launch aircraft. Simulation results for the critical positions are correlated with full-scale data. Finally, the implications on cruise missile design, operations, and flight testing are discussed in broad terms.

INTRODUCTION

Designers have faced a myriad of design and test problems in analyzing and demonstrating the separation of weapons or other stores from a parent aircraft. Accompanying the normal problems, with the air-launched cruise missile (ALCM), the separating vehicle has all its aerodynamic surfaces folded and must make critical maneuvers right after separation. Thus, the designer faces additional challenges with ALCM. The problems were recognized early during the subsonic cruise armed decoy (SCAD) program, and development programs were initiated to solve the complex problems within severe configuration constraints on weight, volume, and aerodynamic configuration. One of the most important contributions of the early ALCM advanced development flight test program was the demonstration of successful launch and jettison of the ALCM-A missile using the B-52/SRAM (short-range attack missile) system.

The AGM-86B (ALCM-B) launch system, which was successfully demonstrated at high and low altitudes during the advanced development program, was designed specifically for the environment and safety considerations associated with the B-52. As the requirements and the design have matured, we have shown a launch capability that exceeds all requirements and goals and that demonstrates a margin of safety for the aircrew. The low-altitude launch capability improves operational survivability because B-52 exposure to defensive systems is lessened during the launch phase.

The AGM-86B launch system has been designed specifically for the B-52 systems, tolerances, and physical envelope. Missile design elements such as surface deployment actuators, flight control gain schedules, empennage sizing, and control actuator requirements were determined from studies of launch from the B-52 weapon bay and pylon. The studies included the effects of carrier motion, B-52 physical envelope, B-52 flow field, and

B-52/SRAM operational software and crew procedures. The same analysis techniques that proved successful on SRAM and the ALCM advanced development program have been used to verify safe and successful launch. This paper describes the launch requirements and the analysis and test techniques plus the data that substantiate the design of the AGM-86B launch system.

LAUNCH REQUIREMENTS

The ALCM system specification requires that the air vehicle be safely and successfully launched within the specified flight envelope. Figure 1 defines the parameters of the envelope and identifies successful launch conditions achieved during the advanced development program. Figure 2 shows the carry and launch positions on the B-52. The inboard and outboard carry positions on the pylons are at 50 degrees from the vertical (center) position.

Safe launches are defined as those having less than a 10^{-5} probability of causing a collision with the carrier. Successful launch is defined as one that meets all system requirements, such as launch fall distance, and all internal or derived requirements, such as preventing excursions beyond the rate and acceleration limits of the missile inertial navigation platform. Figure 3 shows the limits for the three axes.

The MAU-12 ejector, part of the SRAM launch system and used also for ALCM ejection, may not provide a perfectly balanced ejection force at its two pistons. Studies from SRAM and the ALCM advanced development program indicate that the imbalance could cause an initial pitch rate as large as 10 degrees per second. This value is used in the present analysis for all launch conditions.

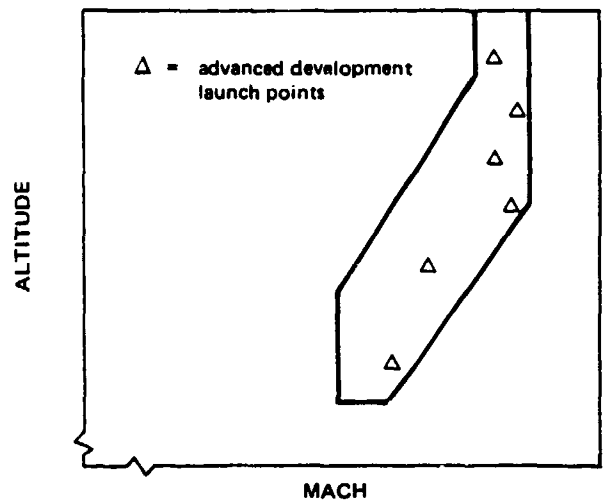

Figure 1. B-52/ALCM Launch Envelope

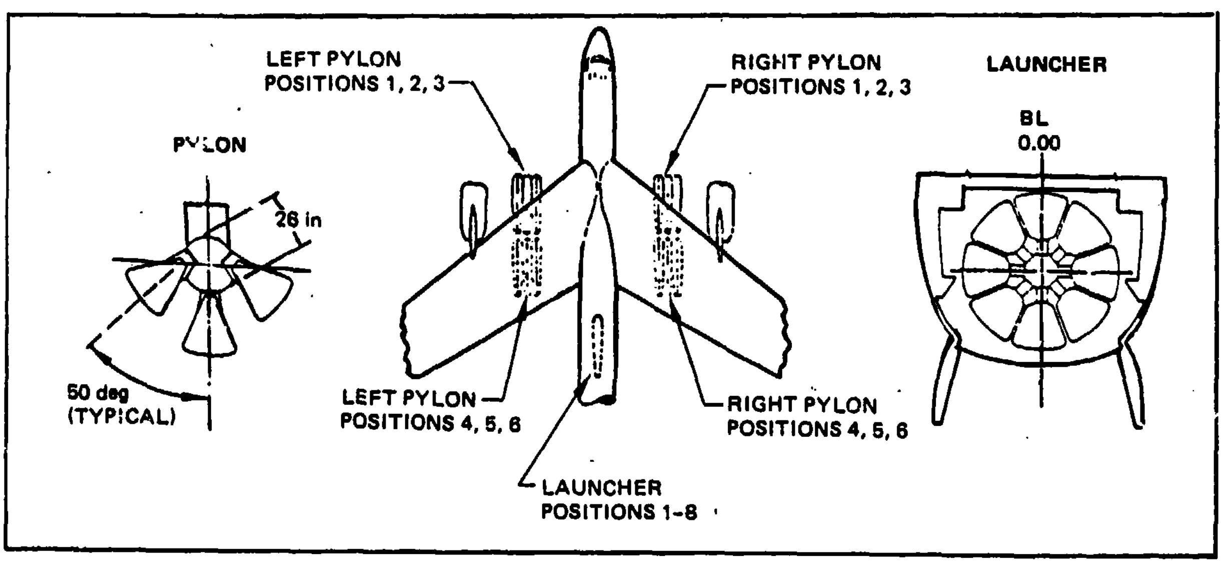

Figure 2. B-52 Carry Positions

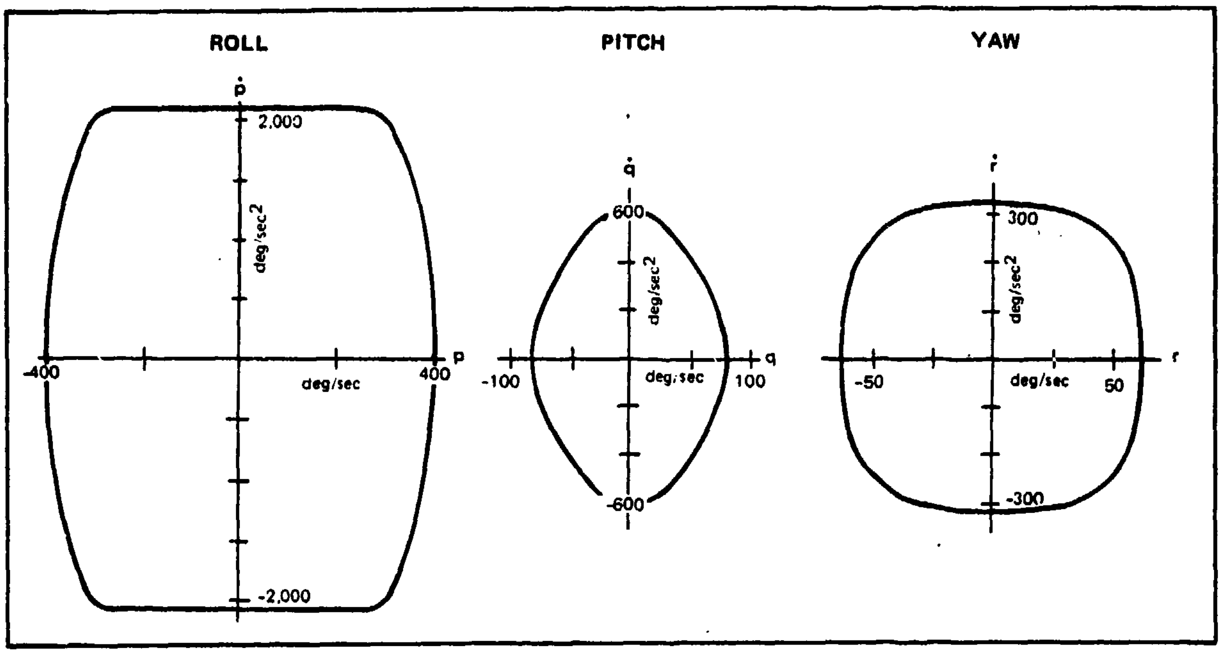

Figure 3. Inertial Navigation Element Rate and Acceleration Limits

The effect of flow field aerodynamics was determined by scale model testing at the CALSPAN wind tunnel facility with a dual-sting mounting arrangement. Forces and moments were measured with and without the B-52 environment, and the differences were computed to arrive at the flow field increments. These have been established as functions of mach number, store location, carrier pitch angle, carrier yaw angle, separation distance, and air vehicle pitch, yaw, and roll angle.

In all, some 320,000 data points have been stored in the launch simulator to define the flow field aerodynamics. Figure 4 shows an example of the variation of moment coefficients with separation distance. These data show an extremely high gradient of forces and moments with separation distance. They also show that the effects of the flow field are difficult to generalize because of large differences between the store locations.

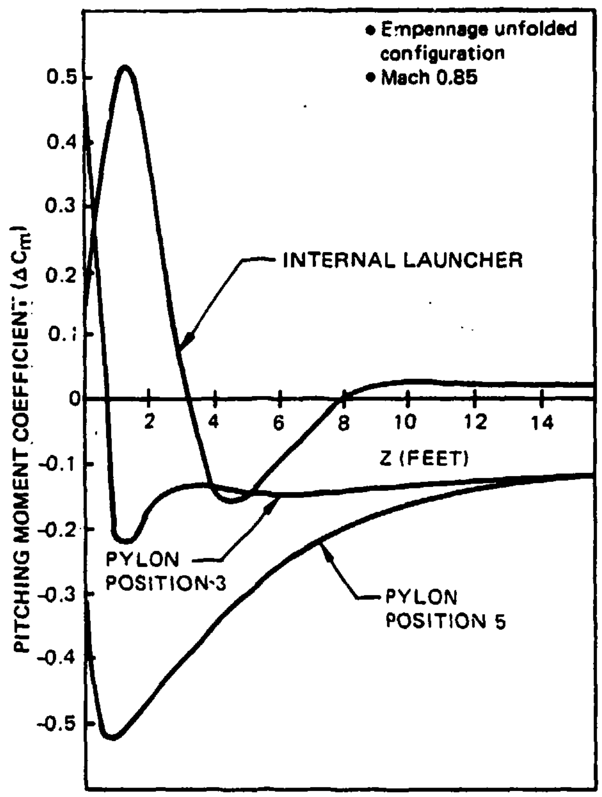

Figure 4. Typical Flow Field Aerodynamic Model—Pitching Moment Coefficient

To reduce the exposure of the carrier aircraft to enemy defenses, a low-altitude launch requirement has been imposed. The ALCM specification defines a requirement for the maximum air vehicle fall distance and a more challenging goal for minimum launch altitude. As described in succeeding text, both the requirement and the goal have been met.

LAUNCH ENVIRONMENT

As the B-52 approaches the launch point, atmospheric disturbances may cause it to deviate from the desired straight-and-level flight. If carrier motions are excessive, launch must be inhibited to avoid a potentially unsafe or unsuccessful launch. To automatically inhibit launch while the carrier is beyond the safe envelope of motion, the SRAM system of attitude rate and acceleration limits was adopted and incorporated in the system specification.

The limiting launch values include carrier accelerations of +2g to -0.5g, roll angle excursions of ± 10 degrees, and pitch angle excursions of ± 10 degrees. During a launch delay, the air vehicle reenters countdown and continues to test for safe, successful launch on the basis of carrier attitudes and motions out to the edges of the envelopes. In several years of SRAM and ALCM flight testing, the carrier level-flight limits have yet to cause a launch delay.

LAUNCH ANALYSIS

The launch simulation has developed during several years of use into a reliable and flexible analytic tool. It is implemented on Harris digital and EASE analog computers. Figure 5 shows a functional flow diagram of the simulation. Major features are: (1) the six-degree-of-freedom equations of motion, (2) a nonlinear analog model of the flight control system, (3) an exact timing and word length representation of the operational software, (4) a nonlinear model of the MAU-12 ejector, (5) a method to introduce wind and gust data, and (6) combined free stream and flow field aerodynamics.

Studies of jettison and launch failure modes involve aerodynamic angles considerably greater than those feasible for 0.4-scale model testing. Experience during the advanced development jettison analysis indicated that analytical estimates of high-angle aerodynamics may not be accurate enough for safety analysis. Therefore, a small, 0.049-scale

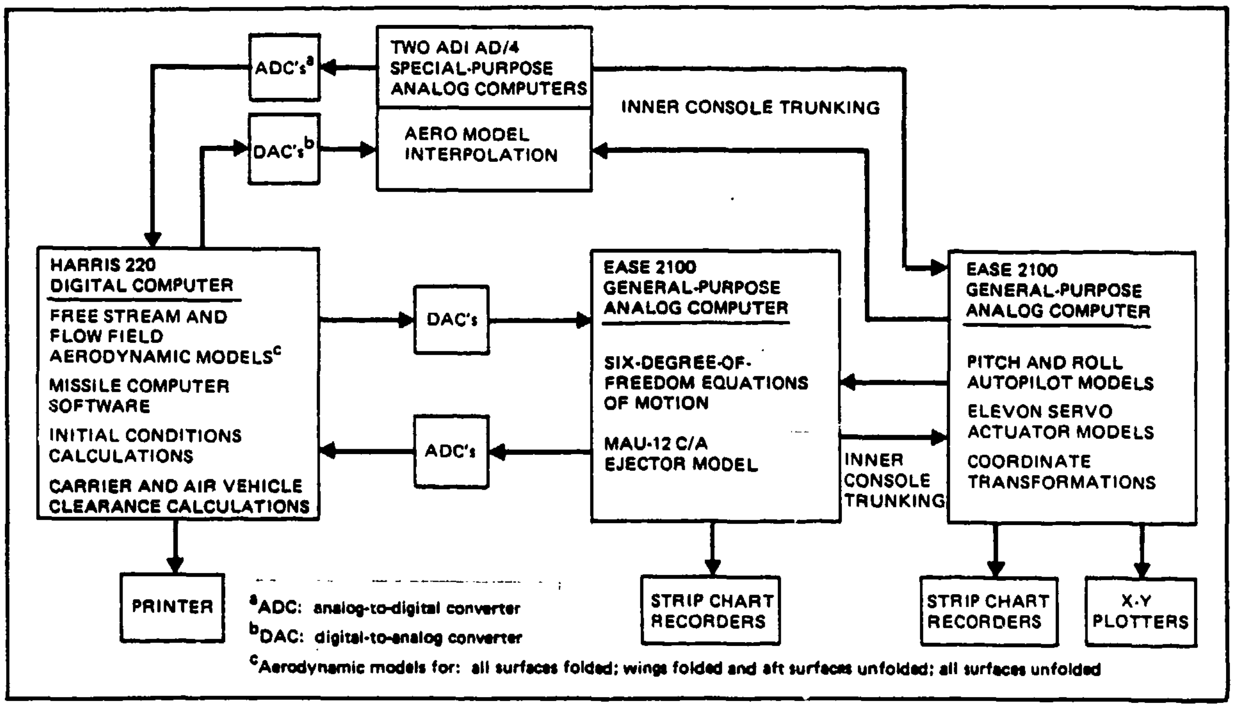

Figure 5. Functional Diagram of Six-Degree-of-Freedom Hybrid Launch Simulation

model was tested in the Boeing Aerospace Company low-speed model tunnel to determine forces and moments as great as 90-degree angles of attack and sideslip. The measurements were used to form the large-angle model used for failure mode and jettison analysis. Figure 6 shows an example of the large-angle aerodynamic model. Large values of pitching moment and normal force appear at high angles; they must be considered in jettison and failure mode analysis.

A simulation can be no more accurate than the modeling of the many pieces of hardware and the environmental forces. All major elements in the Boeing launch simulation have been compared to ground-test or flight-test data and corrected where necessary. Figure 7 illustrates several sources of update information.

LAUNCH SYSTEM

The launch simulation has been used for parametric studies to define elements of the launch system. The launch time-line for pylon and weapon bay launches is shown in figure 8. The indicated times are based on computer clock time, which starts when the computer receives the separation signal from the separation switch. This occurs about 110 milliseconds (ms) after first motion. Typical deployment time durations are 110 ms for the elevon, 150 ms for the fin, and 800 ms for the wing. Therefore, for pylon launch, the elevons have completed their deployment by 0.22 second, and the missile has attained full cruise configuration by 1.91 seconds. These timelines allow adequate spatial separation during deployment and still achieve early control of the air vehicle.

A study of jettisons from various store locations and in various flight conditions shows that, without the surfaces deployed, large angular rates are attained rapidly. Early and rapid empennage deployment is necessary to inhibit angular rate development and to prevent large angular excursions. Pyrotechnic deployment actuators are needed to achieve

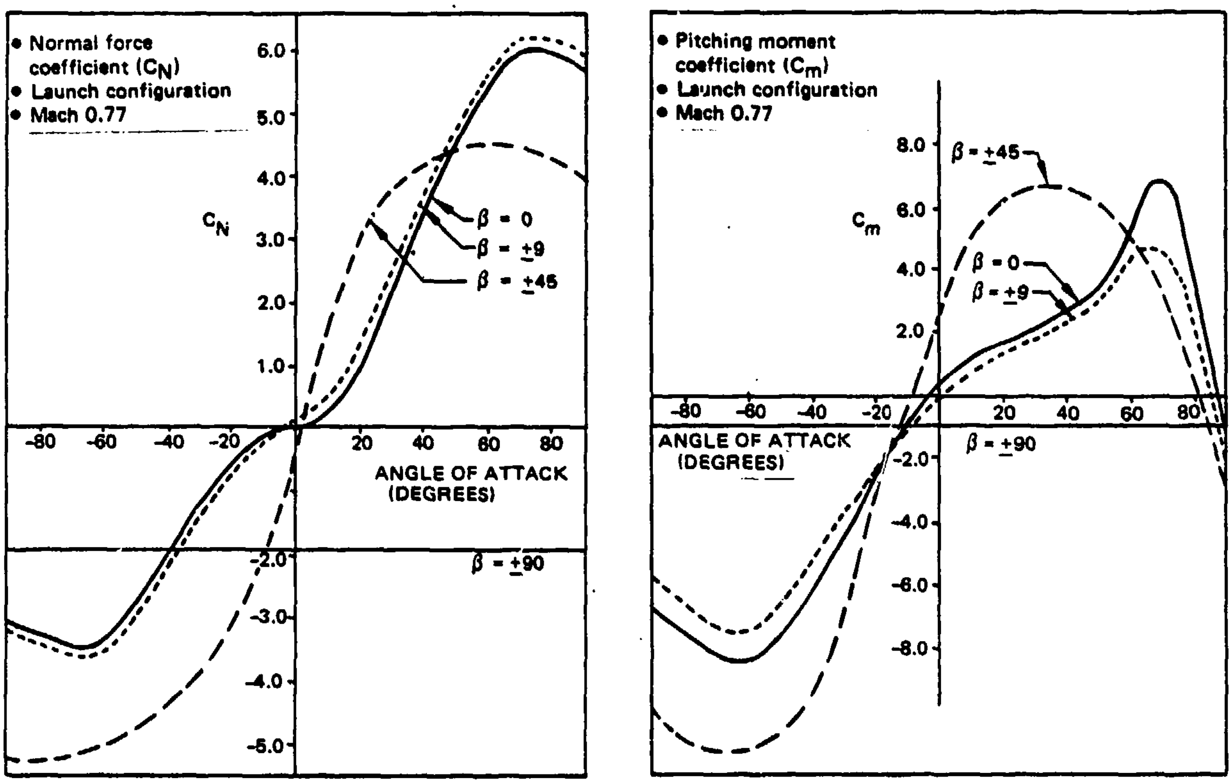

Figure 6. Typical Large-Angle Aerodynamic Model

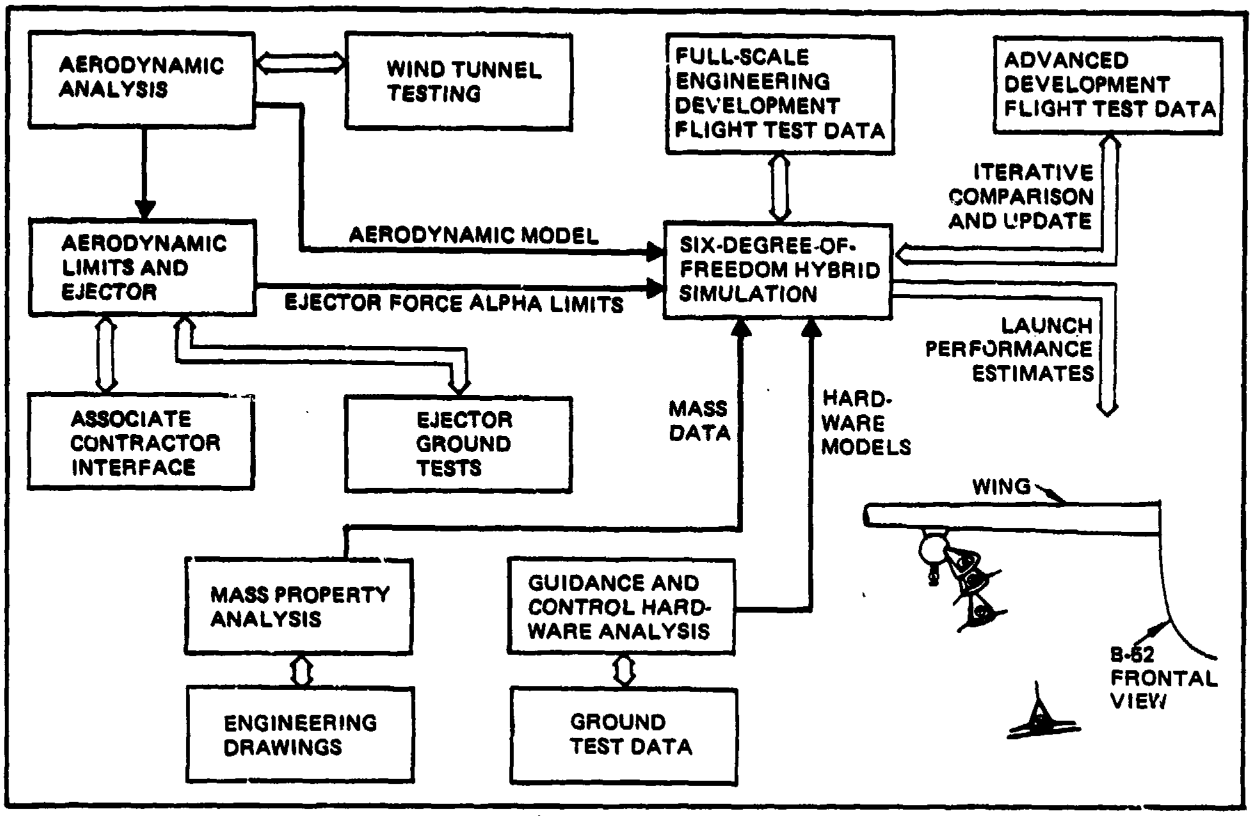

Figure 7. Launch Analysis Information Sources

Event	Time after separation (seconds)	
	Launch position	
	Internal launcher	Pylon
Enable elevon control actuators	0.100	0.0
Issue elevon unfold discrete	0.125	0.0
Issue fin unfold discrete	0.300	0.150
Start autopilot commands to elevon control actuators	0.375	0.175
Issue engine start cartridge discrete	0.500	0.500
Issue wing unfold discrete	1.000	1.000
Perform postlaunch safety check	1 → 3	1 → 3
Change elevon pitch command limiter from launch to cruise limit value	3.000	3.000

TIMELINES

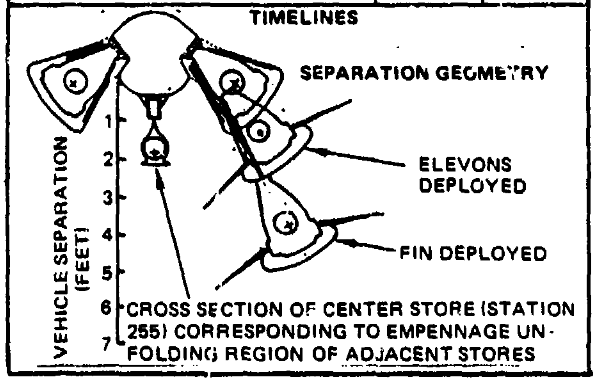

Figure 8. Launch Timelines

rapid deployment and overcome the high aerodynamic loads.

During launch recovery, the aerodynamic configuration rapidly transforms from an uncontrolled, unstable vehicle to a stable, controlled one. The gains for the flight control system must change rapidly during launch recovery to account for the changing aerodynamic configuration and to schedule the angle of attack for rapid pullup.

LAUNCH PERFORMANCE

The launch simulation has been used to determine the AGM-86B launch performance. Figure 9 shows launches from two store locations. The launch recovery transients must be assessed on the basis of two main criteria: (1) attitude angle, attitude rate, and acceleration amplitude; and (2) potential hazard in the event of a failure. For example, the center pylon locations have a nose-down flow field and

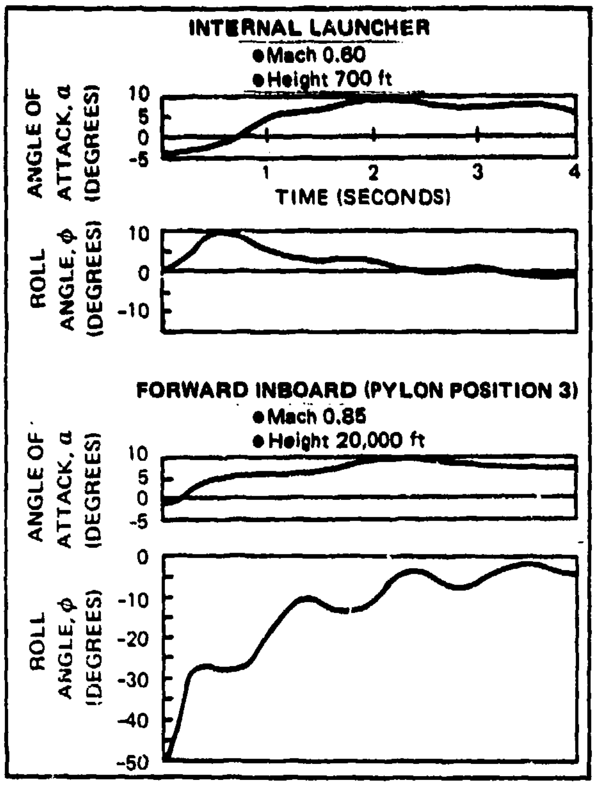

Figure 9. Typical Launch Recovery Transients

tend to be critical for large angle transients and fall distances. The launcher location has a strong nose-up tendency and is critical for nose-up failure modes. The diagonal pylon locations, particularly inboard, tend to have large lateral and directional disturbances and are critical for large roll angles and rates. Each of these situations has been analyzed and tolerances have been established to ensure that the system will meet safety and performance requirements.

To allow continuous low-altitude penetration of the carrier vehicle, the cruise missile must be launched at low clearance altitude. Figure 10 summarizes low-altitude launch performance.

The full maneuver capability is applied in less than 2 seconds after launch and is of sufficient magnitude to arrest the sink rate within 5 seconds, under nominal conditions. At the specified conditions of mach and pressure altitude, the missile can be launched at an altitude 20% lower than the goal and still remain above the specified minimum ground clearance. The same launch altitude can also be attained at higher pressure altitudes by increasing the launch mach number. Such performance capability allows for uncertainties in missile aerodynamics and also accounts for permissible carrier aircraft sink rate at missile launch.

LAUNCH EXPERIENCE

Extensive flight test experience with missile separation has been acquired during SRAM testing and the ALCM advanced development tests. The launch simulation was validated by comparing flight data to predictions and making corrections, including–

a. The aerodynamic damping increments associated with the rapidly opening surfaces were deleted. The predicted perturbations were not observed during flight tests.

b. Normal force and pitching moment coefficients at high angles of attack were increased. Analysis of advanced development program jettison test data indicated the need for this change and led to the imposition of large-angle, small-scale testing for the full-scale engineering development phase.

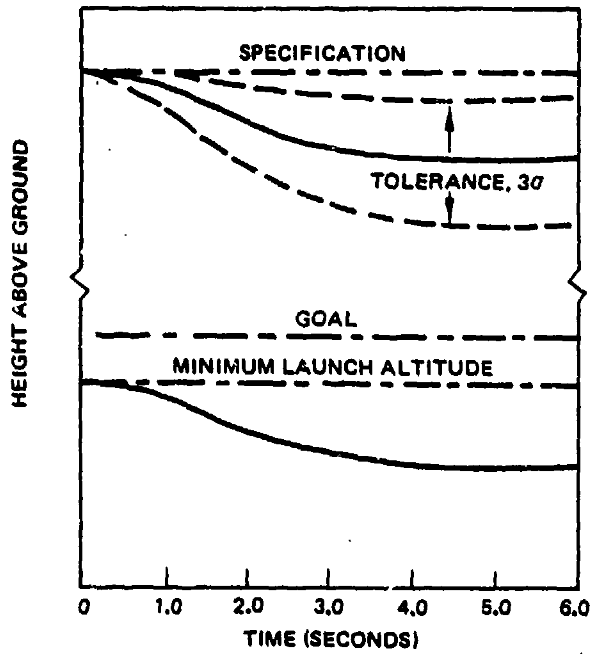

Figure 10. Low-Altitude Launch

Figure 11 compares actual attitude excursions and separation trajectory during launch recovery of the first advanced development program flight test. The comparison and matching process was continued for each of the advanced development flights. Each of the comparisons showed close correlation, thus validating the simulation.

LAUNCH SAFETY ANALYSIS

The requirement for a safe launch specifies that the probability of a hazardous condition must be less than 10^{-5}. In addition, Boeing Aerospace Company has added another design guideline: No single failure may cause a collision with the carrier. This guideline has been implemented in the design and has resulted in the following design features:

a. A postlaunch safety check monitors separation velocity and commands an evasive maneuver if the separation velocity crosses a hazardous threshold.

b. A servo feedback monitor has been added in the prelaunch test of the missile avionics.

The launch safety analysis ensured the following—

a. No single failure will result in an air vehicle and carrier collision.

b. Multiple failures that could cause a collision are within the specified probability allocation.

The launch safety analysis was performed in two parts:

a. A launch simulation study identified the fault conditions that could cause an air vehicle and carrier collision. Figure 12 shows a portion of a matrix of fault conditions. Such a tool shows which combinations of fault conditions can be hazardous.

b. The fault conditions identified in the simulation were then evaluated by a fault tree analysis, which is shown in figure 13. The analysis determined what hardware failure modes combine to cause the fault conditions that could result in a collision and

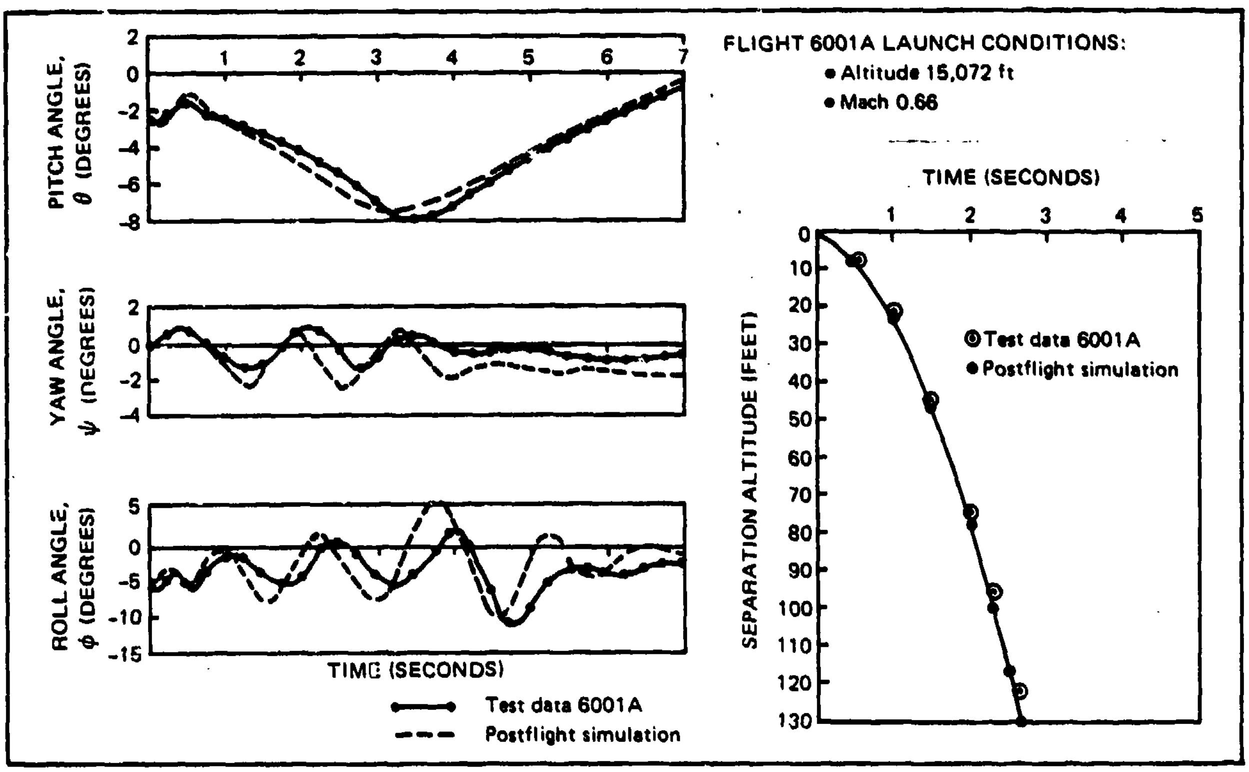

Figure 11. Advanced Development Flight Test Comparison

AIR VEHICLE												B-52								
ELEVONS						FIN			WINGS			EJECTOR			FLIGHT CONDITIONS					
		LOCKED																		
NOT DEPLOYED	NOT LOCKED	ELEVON CMD NORMAL	ELEVONS CMD PITCH HARD UP	ELEVONS CMD MAXIMUM ROLL	NO ELEVON COMMAND	DEPLOYED NORMAL	NOT LOCKED	NOT DEPLOYED	DEPLOYED NORMAL	DEPLOYED EARLY	NOT DEPLOYED	NORMAL EJECTION	ZERO VELOCITY EJECTION	FORWARD PISTON LOCKED	MAXIMUM Q	NEGATIVE PITCH RATE	PITCH NORMAL	NEGATIVE PITCH	NEGATIVE VERTICAL TRANSLATION	EXCESSIVE ROLL RATE
X						X				X				X		X				
				X		X				X										

Note: Failure modes are those used in the launch safety aerodynamic model

Figure 12. Sample Launch Safety Analysis

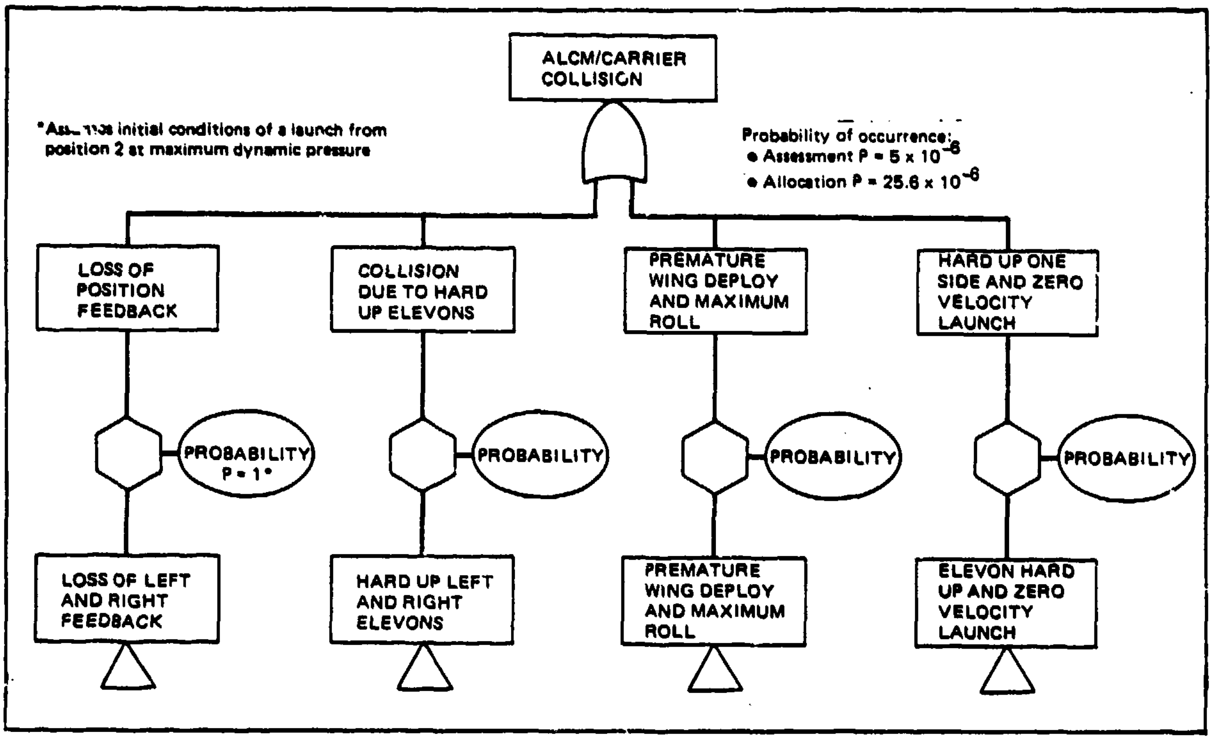

Figure 13. Fault Tree Analysis

assessed the probability of occurrence of the failure modes.

The results of the launch safety analysis indicate that—

a. The ALCM system meets the safety specification probability allocation.
b. No single failure will result in a collision of the air vehicle and the B-52.

JETTISON REQUIREMENTS

The AGM-86B must be capable of safe jettison from any carry position whenever the B-52 is within the mach-altitude envelope of figure 14. A detailed six-degree-of-freedom simulation must demonstrate this capability, and flight tests must verify it.

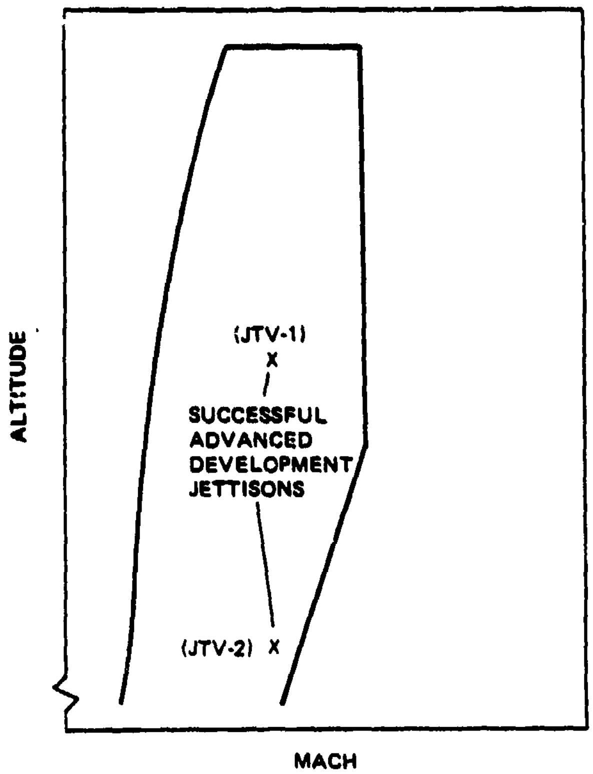

Figure 14. Jettison Envelope

JETTISON EXPERIENCE

Boeing tests have involved the jettisoning of many vehicles from the B-52 carrier from pylons and the internal launcher. During the advanced development program, two jettison tests were successfully completed from the internal launcher. The first test was at a low dynamic pressure (q); the second, at a high-q condition. The approximate mach and altitude conditions of these tests are marked on the jettison envelope in figure 14. Many jettison tests from the pylon and launcher have been conducted during the SRAM program.

Currently, four jettisons of the AGM-86B configuration have been completed successfully. The tests included one each from the forward center and forward inboard locations and two from the launcher. A film presentation shows the separation trajectories, which agreed closely with predictions. These tests, as well as previous SRAM and advanced development program jettisons, have been successfully completed with no hazard to the carrier.

This test experience has thoroughly verified the procedures and analytic methods to accurately simulate jettison trajectories in the vicinity of the carrier. Key elements of the simulation, such as ejector characteristics, aerodynamic free stream and flow field definition, plus carrier motion and geometry, have all been validated by corresponding flight test data.

Figure 15 compares advanced development high-q jettison test data with the simulation predictions. As shown, the predictions and test data agree closely, thus lending a high degree of confidence that operational jettison conditions can be predicted accurately.

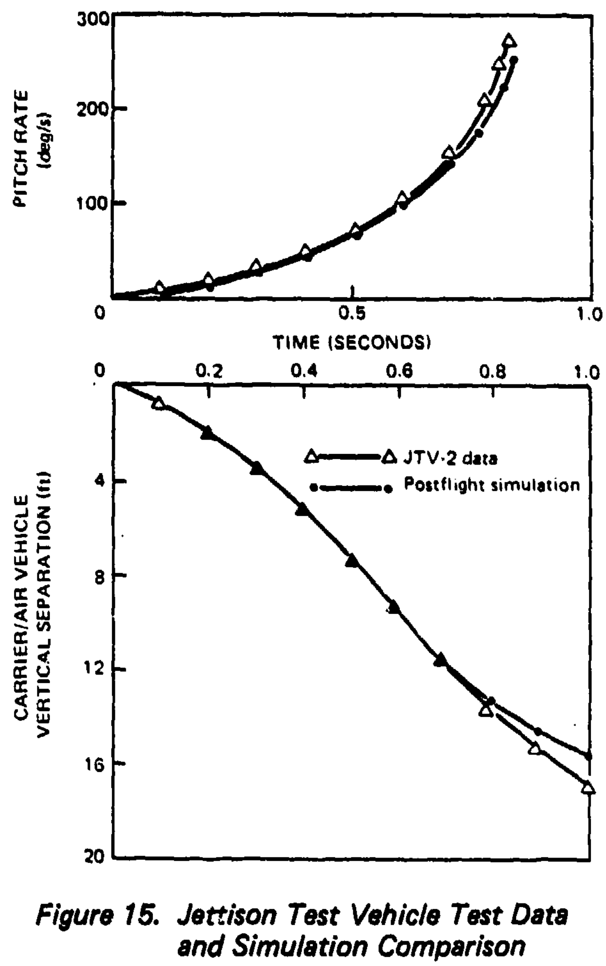

Figure 15. Jettison Test Vehicle Test Data and Simulation Comparison

OPERATIONAL JETTISON TRAJECTORIES

Simulation studies have prediced jettison trajectories for each of the launch positions at the extreme corners of the jettison envelope. Figure 16 shows the trajectory resulting from an internal launcher jettison for four flight conditions. The flow field influence on jettison from the launcher increases as mach number is reduced from 0.85 to 0.60. A full set of adjacent stores in the internal launcher increases the nose-up pitching moment significantly. The four jettisons shown in figure 16 are all with a full launcher. As expected, the worst case jettison condition occurs at the low-altitude, high-mach corner of the envelope. Under these conditions, the missile safely clears the B-52 and presents no hazard to the carrier.

Tolerances must be calculated to thoroughly analyze jettison capability. Tolerances include carrier motion, ejector performance, and aerodynamic uncertainties. Table 1 lists the tolerances and their ranges that have been simulated for the various launch positions.

Table 1. Jettison Tolerance Conditions

Parameter	Analysis excursions
1) Ejector force	+37%, -27%
2) Ejector-induced pitch rate	50% imbalance in ejector piston forces
3) Wind gusts	±20 (1 - cos (ωt)), ft/s
4) Flow field factor	±25%
5) Mass properties	cg: body station 131 to 135
6) Carrier motion	System specification, 2182001B, 6.1,e.

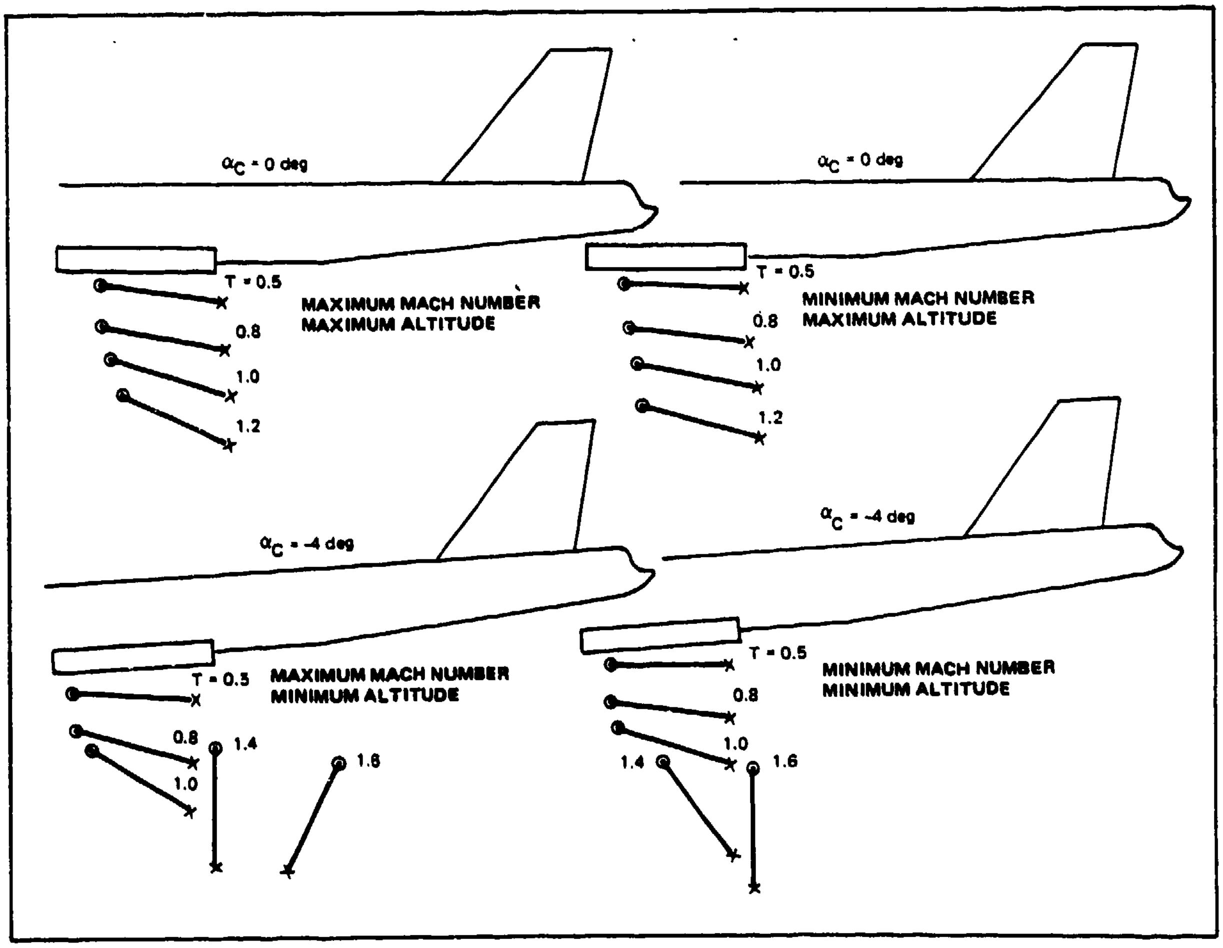

Figure 16. Jettison Trajectories From Internal Launcher

Besides jettison tolerances, the investigation included the effects of ejector failure modes on air vehicle trajectories. Failure modes considered were zero ejector force and zero force from the forward ejector piston but nominal aft piston force. The latter mode produces the maximum nose-up pitching moment.

The tolerance data have been used to determine the margins of safety for the various jettison conditions.

CONCLUSIONS

The launch and jettison analysis of the AGM-86B has progressed over several years of effort dating back to the early 1960's with the SRAM program. The problems have been difficult because several disciplines and stringent constraints have been involved. For example, aerodynamic and flight control considerations determine the structural requirements for deployment actuators. These requirements are also influenced by avionic timing capabilities through relays and software delays. But these structural requirements are constrained by available volume as determined by internal equipment and external aerodynamic shape.

Experience gained in many ground and flight test programs has been used to improve the models of the various simulation elements. Present analysis of the operational configuration of AGM-86B indicates that all of the operational ALCM launch and jettison requirements and goals will be satisfied. The excellent low-altitude launch capabilities of the AGM-86B system will improve the effectiveness of the B-52 cruise missile force.

ADVANCES IN

ANTI-JAM TRANSMISSION OF

RECONNAISSANCE IMAGERY DATA

By Ed Greenwood

May 30, 1979

ABSTRACT

ADVANCES IN ANTI-JAM TRANSMISSION OF RECONNAISSANCE IMAGERY DATA

Very high data rate reconnaissance sensors are used in non-preprogrammed remote control vehicles that utilize video data links. These systems require video bandwidth reduction to reduce their susceptibility to jamming in a hostile electronic warfare environment.

Today's semiconductor technology can achieve data rate reductions that depend on the system application. Degradation of the video data can be negligible for many purposes. High density, low power semiconductor memories and signal processing devices are being applied. No acceptable metric of video quality for humans exists today. Semiconductor development of special devices presents schedule constraints that need improvement or advanced start times.

Today's systems can utilize straight-forward techniques with a mix of special semiconductor devices and existing semiconductor devices. Future systems can achieve greater bandwidth reductions and be even smaller with the use of 100% VLSI devices.

The RF communication of real time video imagery data has only recently considered jam resistant techniques, except for link margins provided by RF power and antenna gain, as well as spatial protection with directional antennas. It is well known that spread spectrum modulation techniques can enhance operation in a hostile electromagnetic environment, but typical video data rates result in unrealistic RF bandwidths for a reasonable amount of jamming protection via spread spectrum techniques. For example, for a 10 megasample/second video signal, sampled with 6 bits/sample, a 30 dB anti-jam (AJ) improvement would result in an RF data rate of 60 gigabits/second. Therefore, the requirement for video bandwidth compression (or reduction) before spectral spreading for AJ is clearly established.

Furthermore, military airborne vehicle requirements impose limitations on size, weight and power to accomplish the bandwidth compression function. Typical missile, glide bomb, and small unmanned airborne vehicle applications impose a power limitation in the order of 20 watts and a size limitation in the order of one or two four inch by six inch modules[1]. With low power silicon gate CMOS VLSI devices, and digital CCD devices, the video data can be processed within the system configuration goals. Video data rates can be reduced from 60 - 80 MBPS to 100 - 400 KBPS,

*depending on the system requirements. Video picture quality is essentially unaltered.**

The key elements in the bandwidth compression function are heavily outlined in Figure 1. The reconstruction of the video is shown in the lower half of the figure. The reconstruction process is not reviewed in this paper because the size, weight and power constraints do not push the state of the art of off-the-shelf components.

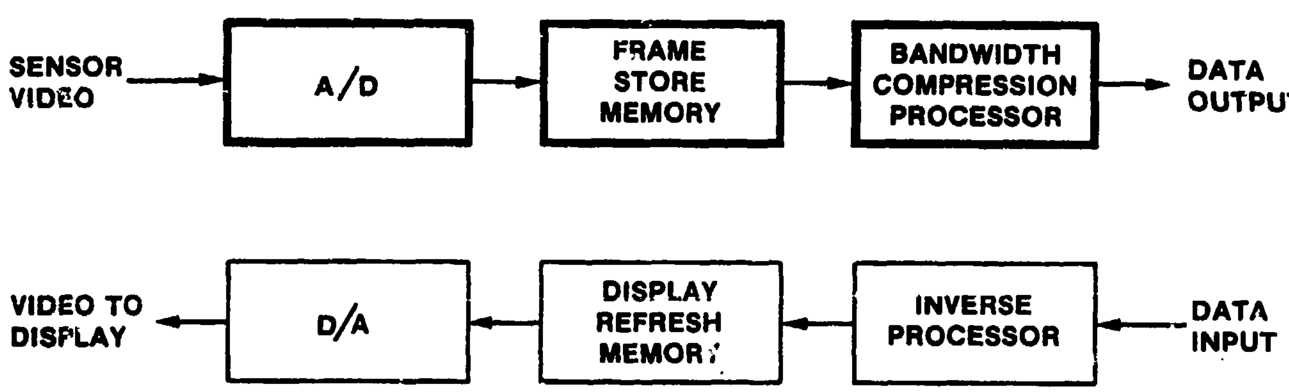

Figure 1 Primary Elements of Bandwidth Compression

**Video quality is a term that is often used throughout this paper. The use of video images must be carefully considered before "video quality" can be truly assessed. The reader is requested to realize that this term is somewhat abused in this paper, but that the writer understands that specific applications will vary the amount of video degradation that is acceptable before "video quality is essentially unaltered".*

Motorola has developed an 8 bit Analog to Digital (A/D) converter and Sample and Hold (S/H) circuit that operates at speeds greater than 12 megasamples/second with a power dissipation of less than 1.5 watts, including all peripheral circuitry. A block diagram of the LSI emitter coupled logic A/D converter is shown in Figure 2. Power dissipation of the chip has been measured at less than 800 milliwatts. The Sample and Hold circuit is a hybrid package (.800" by .800" in size). As shown in Figure 3, it utilizes the voltage reference that is part of the LSI A/D converter chip. This sample and hold and A/D converter were recently delivered to the Air Force Avionics Lab (AFAL) for evaluation.

The A/D converter is a key element since it allows the use of VLSI digital memory devices. The frame store memory stores one frame of sensor data (e.g., one 30 frame/second television frame), allows transmission of this stored frame at a slower rate required by the system user. This choice of transmission rates is uninhibited because of the use of digital storage devices. Furthermore, digital storage devices can be readily designed to accommodate any number of bits/sample, which is dependent only on the A/D converter quality. Also, available digital devices are compatible with typical military environments. Figure 4 shows a television frame store memory that was designed, built, and

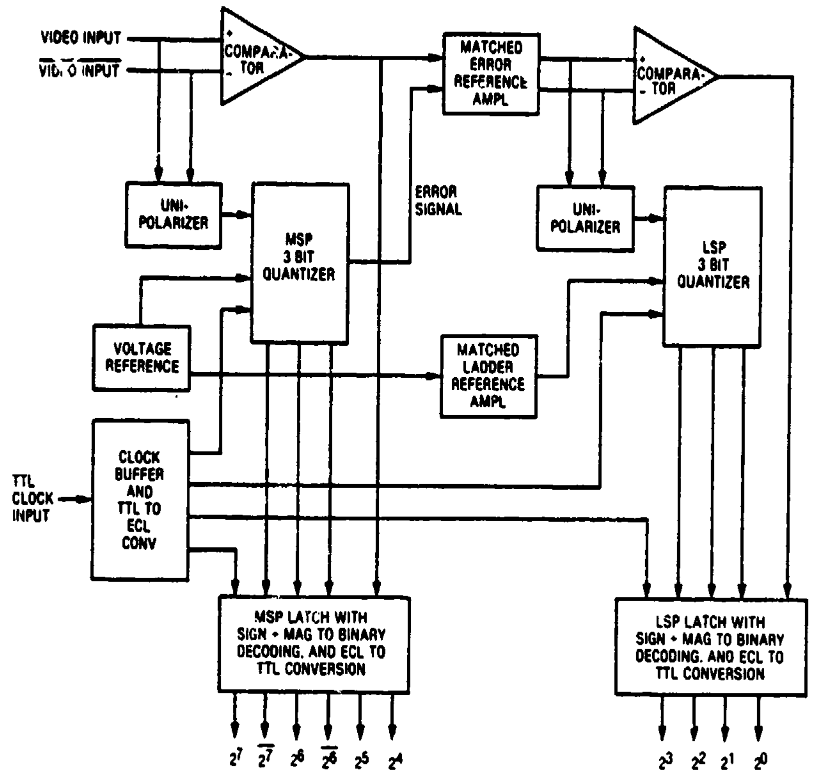

Figure 2 A/D Converter Block Diagram

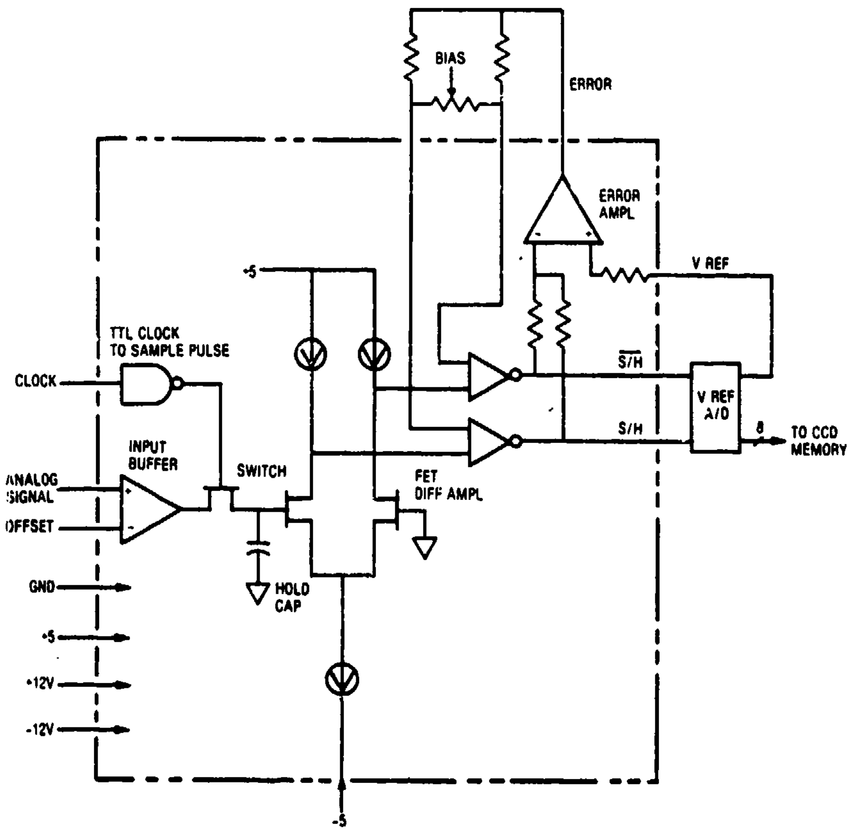

Figure 3 Sample and Hold Block Diagram

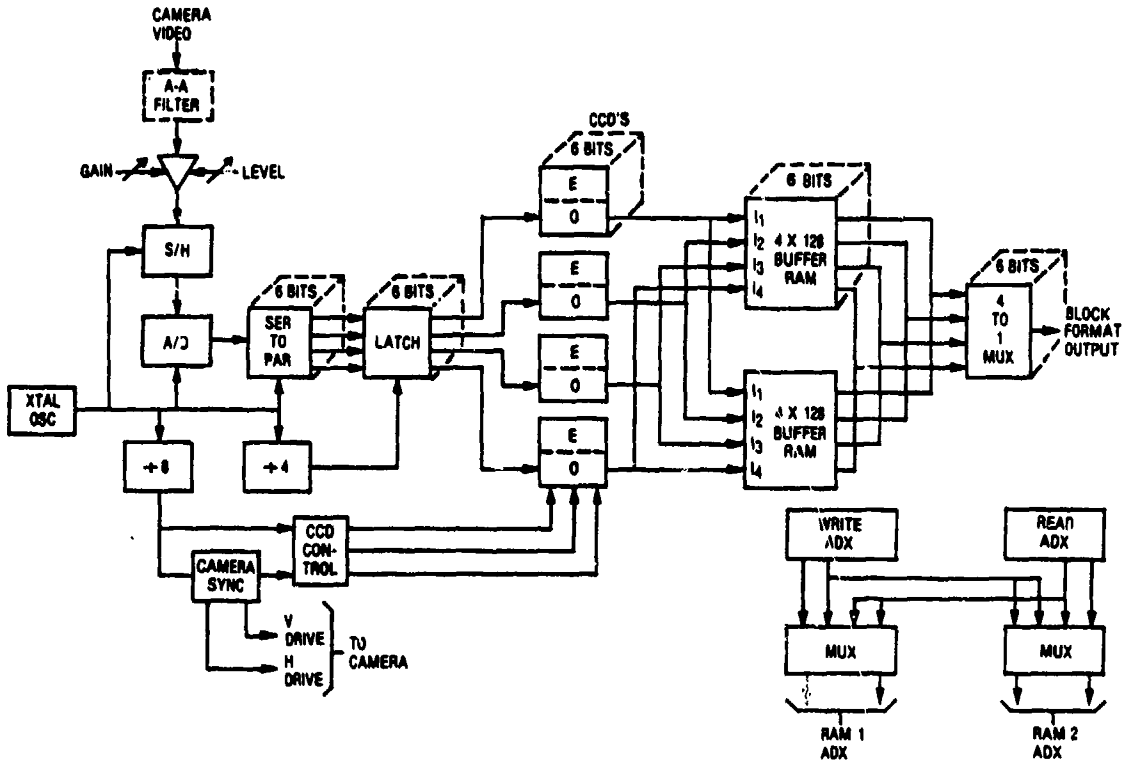

Figure 4 Frame Store Memory Block Diagram

TABLE 1

POWER DISSIPATION OF FRAME STORE MEMORY

Functional Description	Estimated Power	Technology
Serial to parallel converter	1.5W	Low power Schottky
CCD Memory Devices and clock drivers	2.4W 3.0W	MOS
Buffer RAM	0.3W	Silicon on Sapphire MOS
Output Register	0.1W	Low power Schottky
Control Logic	3.5W	LS TTL and MOS
TOTAL	10.8W	

tested for AFAL[2]. The video quality of 512 samples per TV line and 6 bits/sample will be shown later in this paper. The reproduction quality of this digitization process is virtually equivalent to monochromatic home television. Table 1 illustrates the device technology used and estimated power dissipation for each functional subelement that makes up the measured 10.8 watts power dissipation of the frame store memory. 64K digital CCD's and high speed, low power silicon on sapphire RAM's are the key memory devices utilized. The parts count required for the operational frame store memory (less A/D and S/H) is shown in Table 2. The frame store memory provides the data output in a format ready to be utilized by the Bandwidth Compression Processor Element.

TABLE 2

PARTS COUNT FOR FRAME STORE MEMORY

Functional Description	6 Bits/Pixel Functional Total	No. Parts at 1 Bit/Pixel
Serial to Parallel Converter	12	2
CCD Memory Devices	24	4
and Driver	6	1
Buffer RAM	12	2
and Register	6	1
Tri-State Buffer	6	1
Control Logic	44	44
TOTAL	110	55

A feasible layout for a miniaturized frame store memory and A/D with S/H is shown in Figure 5. This potential package configuration utilizes common hybrid packages to the greatest extent feasible. This miniaturized unit could operate in a closed package that had to function in a -54°C to +70°C outside temperature environment.

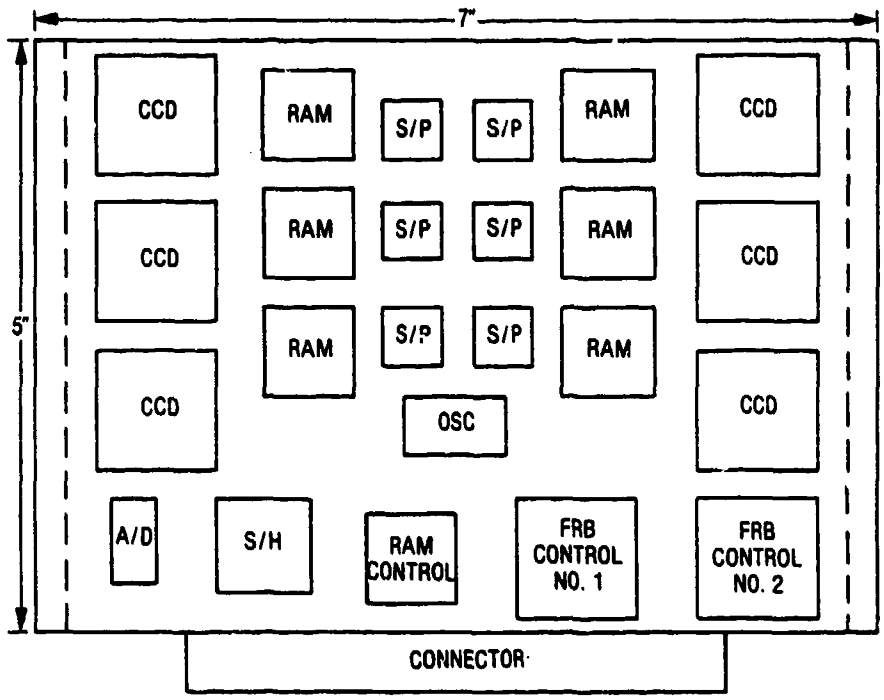

Figure 5 Frame Store Memory
Miniaturized Package Concept

The Bandwidth Compression Processor utilizes algorithms that take advantage of the correlation of the video data in the image spatial domain. The correlation of the video data is partially due to the object spatial correlation

properties and is partially due to the aperture scanning process in the video sensor device. Transforms (and other algorithms) are utilized to redistribute the video co-efficients' image energy (which tends to be uniformly distributed in the image spatial domain) so that the majority of the energy is contained in a small percentage of the transformed coefficients. Of course, processing can be done on a vector basis (one-dimensional transform) or on a block matrix basis (two-dimensional transforms). In general, 2-dimensional processing performs better, as it takes advantage of the line-to-line correlation in the video data.

Two types of transforms have been investigated for implementation by Motorola[3], namely the Cosine transform and the Hadamard transform. One of the key difficulties in selecting a transform for implementation is that there is no acceptable metric (that is, a mathematical measure) for video quality that correlates to the video quality as measured by the human visual system. Hence, processor complexity trade-offs versus improvement in video quality for the user is largely judgemental today. As a result of this problem, Motorola (and other groups in this field) have implemented extensive simulation facilities. A block diagram of the present Motorola facility is shown in

Figure 6. This allows comparison of television monochromatic images without developing specific hardware to accomplish various processing algorithms.

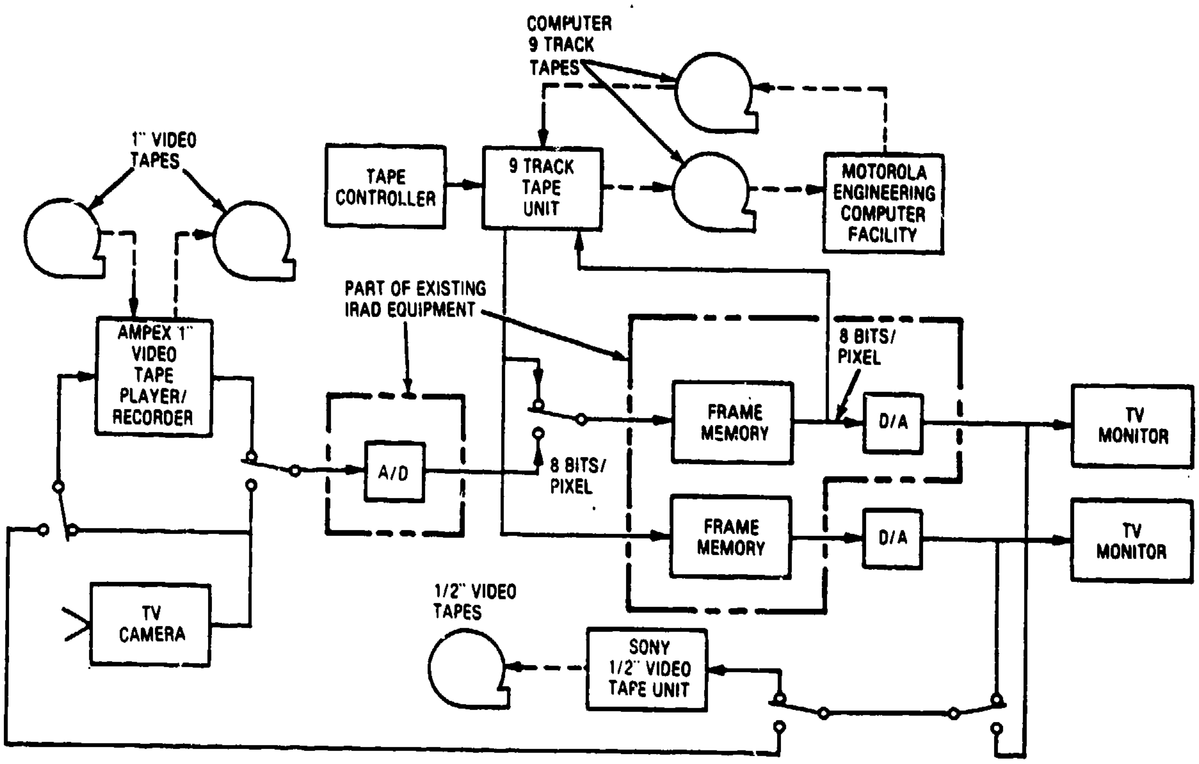

Figure 6 Motorola Video Bandwidth Compression Simulation Facility

Motorola is presently under contract to AFAL for development of a two-dimensional Hadamard transform Bandwidth Compression breadboard system[4]. One mode of this system requires 512 x 512 resolution elements (pixels) transmitted at 15/32 frames/second. Table 3 illustrates the power dissipation and parts count for a miniaturized

configuration of this breadboard. The breadboard system uses a custom LSI silicon gate CMOS device that has been built and tested.

TABLE 3

2D HADAMARD MINIATURIZED BANDWIDTH COMPRESSION PROCESSOR (512 x 512 AT 15/32 FPS)

- **TRANSFORM PROCESSOR**
  - 1 CUSTOM LSI DEVICE USED ONCE
  - 1.11 WATTS
  - 32 PARTS
  - 2 HYBRID PACKAGES
- **ZONAL CODER:**
  - 0.78 WATTS
  - 29 PARTS
  - 2 HYBRID PACKAGES
- **PRINTED WIRING BOARD PACKAGE:**
  - SINGLE SIDED MOUNTING
  - 3.5 INCHES X 3.5 INCHES
  - TOTAL POWER = 1.89 WATTS
  - THERMAL DENSITY = 0.154 WATTS/INCHES^2

An example of the quality obtained with the A/D, frame store memory and Hadamard transform is shown by Figures 7, 8 and 9[3]. Figure 7 is a 512 x 480 pixel (sample points) by 6 bits per sample prior to bandwidth compression processing. Figure 8 is the same picture that was bandwidth reduced to an average of 1.5 bits/pixel and then reconstructed (using a two-dimensional 8 point by 8 point Hadamard transform processor). Figure 9 shows the same picture bandwidth reduced

Figure 7 Original at 6 bits/pixel

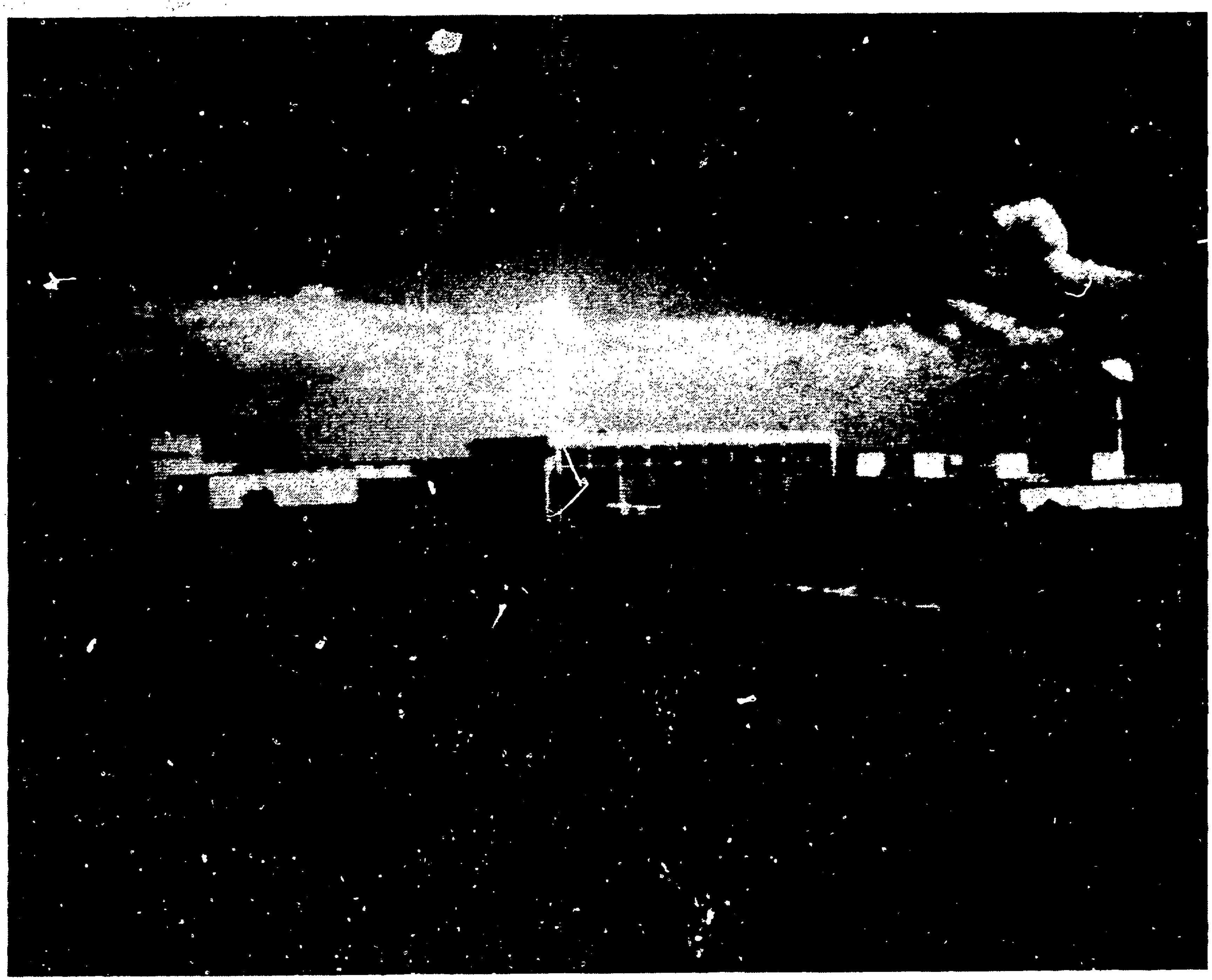

Figure 8 Processed at 1.5 bits/pixel

Figure 9 Processed at 1.0 bits/pixel

to 1.0 bit/pixel average rate and then reconstructed.

A cosine transform processor has recently been considered for implementation that would require development of three custom LSI state of the art Silicon gate CMOS devices. Table 4 shows the parts count and power dissipation of this design. A feasible printed wiring board layout of this design is shown in Figure 10. The power savings of the three custom LSI devices is seen by comparing the 1979 cosine equipment characteristics with the 1981 cosine equipment characteristics shown in Table 6. This savings in power also allows hybrid packaging and its associated reduction in size. This savings is possible if an additional year is allowed in the schedule to design, fabricate, and test the custom LSI devices.

Picture comparisons using cosine processing versus Hadamard processing show the cosine processor provides a slight improvement in picture quality. These comparisons were made using the Motorola Video Bandwidth Compression Simulation Facility.

Another problem in the application of technology for these requirements is illustrated by Table 5 and Table 6. The volatility of the semiconductor technology is reflected

TABLE 4

2D COSINE MINIATURIZED BANDWIDTH
COMPRESSION PROCESSOR
(512 x 512 AT 7.5 FPS)

- **TRANSFORM PROCESSOR:**
  - 3 CUSTOM LSI DEVICES; EACH USED FOUR TIMES
  - 1.608 WATTS
  - 26 PARTS TOTAL
  - 2 HYBRID PACKAGES
- **ZONAL CODER:**
  - 1.710 WATTS
  - 36 PARTS
  - 2 HYBRID PACKAGES
- **TIMING:**
  - 0.160 WATTS
  - 7 PARTS
  - 1 HYBRID PACKAGE
- **TOTAL POWER: 3.478 WATTS**
- **THERMAL DENSITY: 0.145 WATTS/INCHES^2**

TABLE 5

A/D AND FRAME STORE MEMORY
HISTORIC SAMPLES

FUNCTION	1976	1979
A/D AND S/H	6 WATTS 25 SQ IN.	1.5 WATTS 2 SQ IN.
DIGITAL CCD FRAME STORE MEMORY	16 K PARTS 19 μWATTS/BIT 6 1/2 MODULES 0.24¢/BIT	64 K PARTS 6.9 μWATTS/BIT 2 MODULES 0.12¢/BIT
DIGITAL RAM FRAME STORE MEMORY	4 K PARTS ≈ 40 μWATTS/BIT ≈24 MODULES >0.25¢/BIT	64 K PARTS ≈4.6 μWATTS/BIT ≈1.8 MODULES 0.19¢/BIT

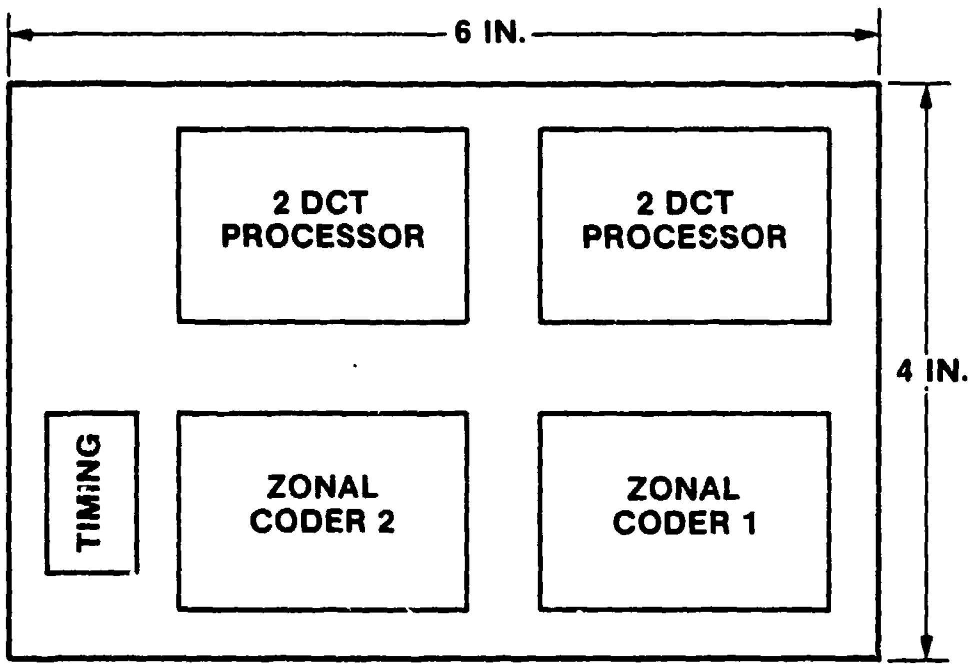

Figure 10 2D Cosine Processing Board Layout

TABLE 6

2D 8 x 8 POINT TRANSFORM
BANDWIDTH COMPRESSION PROCESSORS

TYPE OF TRANSFORM	1976	1979	1981
HADAMARD	[≈25 WATTS 3 MODULES]	[≈8 WATTS 1/2 MODULE]	≈2 WATTS 1/4 MODULE
COSINE	— ≈8 MODULES	≈12 WATTS ≈2 MODULES	[≈4 WATTS 1 MODULE]

[ ] DENOTE POINT DESIGNS

in the RAM/CCD comparisons in Table 5. If eventual unit production cost were an important parameter in the present day design of a frame store memory, the decision could be difficult. The CCD technology is such that they should be less expensive to manufacture than the RAM's. But the market demand for the RAM's may soon result in a lower RAM cost.

Table 6 shows the impact of semiconductor technology on state of the art configurations of two types of transform processors. This dynamic technology, coupled with the judgemental video quality measure, makes for very nebulous system trade-offs, especially if the system requirements are not carefully delineated.

The present day technology allows the use of custom LSI devices, along with off the shelf devices to provide video bandwidth reduction for less than 20 watts and for 2 modules of space allocation. Of course, custom LSI devices may present schedule constraints. Careful examination of the system requirements, coupled with simulations of representative data, are recommended before design of the bandwidth compression system. If 100% custom VLSI devices can be utilized, the above size and power can be reduced substantially.

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(3) Final Report 7243, Task I, Video Bandwidth Compression, by Ed Greenwood, Motorola Government Electronics Division, Scottsdale, Arizona, August 7, 1978.

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UNMANNED SEAPLANES FOR NAVAL OPERATIONS

by

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ABSTRACT

The technical advances making unmanned seaplanes practical are reviewed with emphasis on aero-hydrodynamics and control technologies. Unmanned seaplanes are shown to provide an attractive combination of flexibility (by virtue of airborne flight) and loiter performance (by loitering afloat). Three conceptual unmanned seaplane designs are presented. These vehicles are designed to fulfill specific naval mission needs in submarine, surface, and air warfare. Comparisons with more conventional systems are presented which show that unmanned seaplanes may offer a very cost-effective solution to future naval warfare requirements.

INTRODUCTION

Aircraft were first designed with hydrodynamically shaped hulls in order to provide basing flexibility and an emergency landing capability for long over-water flights. In these early days of aviation these types of aircraft, called seaplanes, were limited to operations in calm water except in emergencies. The addition of the hull resulted in higher structural weight and higher aerodynamic drag compared to land-based aircraft. As aeronautical technology advanced, airfields became more numerous and aircraft systems became more reliable. Aircraft performance also improved making the penalties for waterborne operation proportionally greater. These factors lead to the demise of the seaplane in the 1950s.

At that time, the Navy began to investigate more innovative seaplane applications. It was thought that seaplanes would be very useful in tactical naval applications if operations could be conducted for rough water and if the aircraft could loiter afloat for extended periods of time. An extensive research and development effort was initiated to achieve this capability. High-lift aerodynamics, refined

hull designs, and hydroskis (and foils) were found to permit routine takeoffs and landings in relatively rough water. Vertical (small waterplane area) floats which supported the seaplane hull above the ocean surface were developed; seakeeping motions with this arrangement were found to be substantially lower than could be achieved with a conventional hull arrangement. These advances, however, required further compromises in aircraft performance and design studies showed that seaplanes using this advanced technology would still not be competitive with land-based aircraft. For this reason, the Navy terminated its seaplane research and development effort in the late 1960s.

In 1975, the David W. Taylor Naval Ship Research and Development Center (DTNSRDC) initiated studies to assess the impact of evolving technologies on the potential performance of advanced manned seaplanes. This effort was supported as part of the Advanced Naval Vehicle Concepts Evaluation (ANVCE). The seaplane hydrodynamics data base was expanded and several advanced seaplane designs were generated and evaluated. Results from these studies showed that manned seaplanes are, and will remain by most measures, uncompetitive with land-based aircraft for tactical naval operations.

A review of the data generated for the ANVCE program revealed that the limited performance characteristic of all seaplane designs was a result of the design constraints imposed by the presence of a crew aboard the aircraft. Habitability requirements for vehicle motion limit the duration a seaplane with a single crew can remain on station. The addition of a second crew can allow the seaplane to loiter for

longer periods, but a severe design penalty is incurred to support the extra personnel.

Within a decade it will be possible to employ unmanned (i.e., remotely piloted) seaplanes for many of the military missions that manned sea loiter aircraft were considered. The removal of the crew for such a vehicle allows for a significant reduction in the compromises in aircraft design needed for human habitation. For instance, vehicle motions while afloat and during takeoff and landing need not be significantly attenuated, and there is little design compromise for longer times on station (avionics reliability and power consumption being the only major limitations). Of course, an unmanned seaplane represents some technical risk. A seaplane has never been routinely operated in even moderate ocean conditions without a man aboard, and even if an unmanned seaplane can be designed, the effects of the marine environment may increase costs and/or decrease performance to intolerable levels. Nonetheless, the concept of an unmanned seaplane is a technical opportunity heretofore uninvestigated. This paper summarizes the major technical issues concerning the unmanned seaplane and presents several conceptual designs oriented at fulfilling specific military applications.

POTENTIAL APPLICATIONS

During the past decade, U.S. supremacy on the high seas has been severely challenged by an unprecedented expansion in Soviet naval forces. All indications point to a continuation of this trend through the end of the 20th century. Compounding this problem are the diminishing

national resources (manpower, fuel, and capital) available within the U.S. to develop, procure, and operate new weapon systems. The U.S. has traditionally relied on a combination of fixed and mobile surveillance systems, attack submarines, surface ships, and land and seabased aircraft to provide a comprehensive sea control capability. All of these systems, and particularly the vehicle systems, require large amounts of these diminishing national resources.

In the 1990's, unmanned seaplanes may be capable of fulfilling some, but not all, the needed sea control missions in ways which reduce requirements for critical national resources, particularly fuel and manpower. In the broadest terms, unmanned seaplanes could be used for missions which can be described as follows:

- Missions where long endurances out to sea are required (but not at high altitude) and/or contact with the sea is desirable (e.g. undersea surveillance).
- Missions where intermittant flight is needed in fast response to a threat (e.g., defensive electronic warfare).

In the latter case, an unmanned seaplane could replace or augment a variety of vehicles which operate as cued systems. Unmanned seaplanes, however, would remain on station (out to sea) awaiting commands to takeoff and perform that same mission. In this way, significantly faster responses would be possible without the need for high transit speeds. A tactical advantage would be derived from covertly maintaining unmanned seaplanes on station since an enemy would then be unable to accurately predict where and when the seaplanes might appear.

Table 1 presents a list of potential unmanned seaplane applications in naval warfare. From the point of view of the unmanned seaplane

vehicles, surveillance missions (which require stationkeeping) are the least demanding, and, at least in the near-term, offer the greatest improvements in cost-effectiveness since aerodynamic high performance is not generally required. Other missions, where an unmanned seaplane would only remain on call while afloat, require more demanding aerodynamic performance (e.g., high dash speed, rate of climb, etc.). Improved cost-effectiveness is more questionable and could be achieved only with greater development risk.

For all these missions, three system characteristics are desirable; these are:

- Small size. Gross weights between 1000 and 50,000 lb (450 and 22,700 kg) are desirable.
- Minimal support requirements. Land-basing is the only reasonable support concept, thus mission radii of the order of 1000 to 2500 nmi (1850 to 4630 km) are needed.
- Minimal data transfer between the seaplane and its controller. In essence, a smart unmanned seaplane is most desirable.

None of these broad characteristics are unrealistic and contemporary technologies, or at most, evolving technologies, will provide the base from which these can be realized. Without these technical capabilities, military applications for unmanned seaplanes would be very limited.

TECHNICAL CONSIDERATIONS

The feasibility of an unmanned seaplane depends on the ability of such a vehicle to routinely operate in rough water. In order for a sea loitering vehicle to take advantage of that capability, operations

in at least State 5 seas* must be possible[1]. This would allow on-water operations in excess of 80 percent of the time worldwide (Figure 1). Higher sea conditions would have to be routinely encountered for operations in areas such as the North Atlantic Ocean and the northern Pacific Ocean. No seaplane, manned or otherwise, has ever routinely operated in water as rough as State 5 seas. This capability constitutes the most critical (and challenging) technical issue concerning the feasibility of an unmanned seaplane. Even if this capability is achieved, a control system must be developed so that the vehicle can operate without a pilot on board. To achieve this goal, the dynamics of takeoff and landing must be well understood. The ability of a relatively small seaplane to remain afloat in rough water for long periods of time without violent motions and loads remains to be demonstrated. These technical issues are critical to the development of a mission-capable unmanned seaplane. Other less critical issues also exist; these include cost-effective payload development and integration, tactics, support concept development, and the effects of the marine environment. The most critical issues are discussed in more detail.

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*State 5 seas are defined as waves characterized by a significant wave height (i.e, the average of the one-third highest waves) of 12.0 ft (3.66 m).

[1]A complete list of references is given on page 18.

TAKEOFF AND LANDING IN ROUGH WATER

In the simplist terms, the size, thrust, and stall speed of a seaplane determine the maximum sea state in which that seaplane can operate (Figure 2). Although technical refinements can yield some improved capability, these three factors make the greatest contribution. Large size (or weight) is a simple (but costly) way to increase the rough water capability of any seaplane. With an unmanned seaplane the relatively small size of these vehicles will have to be overcome by high installed thrust and low stall speed. An obvious solution would be to use such high thrust that vertical takeoffs and landings (VTOL) would be possible. For all practical purposes, an unmanned VTOL seaplane would not be restricted by rough water (although the attendant wind conditions might prove prohibitive). However, VTOL aircraft given current and near-term future propulsion technologies will not permit a practical unmanned VTOL seaplane to have sufficient range-payload performance for naval warfare missions. Another problem with VTOL operation is the high degree of control required during takeoff and landing. In any unmanned vehicle control requirements, particularly for real time control, must be minimized, the unmanned seaplane is no exception.

An alternative solution is to employ relatively high thrust and lift to achieve a Short Takeoff and Landing (STOL) capability. If short takeoff and landing distances can be achieved (less than 500 ft (150 m), that is, in one or two wave lengths) then slamming motions and loads could be minimized. During takeoff, the aircraft

would become airborne at speeds below stall and have a ballistic flight trajectory due to travelling up the face of the last wave, this is commonly called "planing-off." Prior to impacting the next wave, the aircraft would accelerate and achieve sufficient velocity to climb out (Figure 3). Planing-off has the advantage of requiring for less installed thrust than VTOL operations, however, a hydrodynamic hull capable of withstanding substantial impact loads must be incorporated into the airframe.

Planing-off has been demonstrated in limited tests with the UF-XS (a modified HU-16) and PS-1 STOL seaplanes[2]. However, the dynamics of planing-off are not well understood. The quantitative effects of winds can only be accounted for with present theories when winds and waves have coincident directions. The possible advantages using hydrodynamic lift enhancing/load aleviation devices, such as hydroskis, has not been investigated. Furthermore, the control requirements for planing-off in rough water are not known, although since the entire takeoff run would be in 5 to 6 seconds, it may be possible to employ configurations with less inherent stability than is typically required. Also, because habitability is not a design constraint, an unmanned seaplane will be able to withstand greater motions and impact loads (structural limits would then become dominant).

CONTROL SYSTEM REQUIREMENTS AND DESIGN

The control of an unmanned seaplane is most demanding during takeoff and landing. As stated previously, it is desirable to minimize the control necessary. Thus, an aero/hydrodynamic configuration

which is inherently stable and can be controlled with minimal sensor feedback is needed. The planing-off phenomenon does allow for such a simple control system, although this has never been demonstrated in the open ocean. Conventional moderate length-to-beam ratio (L/B) hulls, with values from 6 to 10, display adequate stability characteristics for unmanned seaplane applications. However, this inherent stability is achieved at the expense of higher hydrodynamic drag and landing impact loads. Most seaplane hull development during the 1960's concentrated on reducing drag and impact loads sacrificing large stability margins, this was possible since all applications included an onboard pilot. Several hull shapes were developed during this period which significantly reduced hull-generated spray and concentrated impact loads. These hull shapes have never been applied to moderate L/B hulls, although they may be quite attractive for unmanned seaplane applications.

Lift enhancement/load alleviation devices, such as hydroskis and foils, could also be used to provide increased stability and/or control power. Theoretical studies[3] have shown that a small hydrofoil can substantially alleviate loads and improve longitudinal stability characteristics. Little weight and drag penalty is involved with such a device, although it does represent a substantial increase in control system complexity. These studies also demonstrated that this arrangement could yield the desired load alleviation by solely incorporating a closed pitch rate feedback loop. Although hydrofoils

offer greater lift enhancement, hydroskis can provide better longitudinal stability characteristics (because there is far less travel of the center of pressure). The application of these devices to unmanned seaplanes has not been investigated. Nonetheless, given the current data base, it is reasonable to assume that a control system can be developed that will allow takeoff and landing in rough water with little or no realtime external control inputs.

LOITERING AFLOAT IN ROUGH WATER

There is very little data available concerning the motions and loads of a relatively small seaplane floating in rough water. Most research has concentrated on relatively large manned vehicles[1,4]. Early studies attempted to reduce seakeeping motions and loads by using a configuration which had natural frequencies well below the typical wave encounter frequency (or at least below the frequencies of waves which contained most of the wave energy), thus an aircraft would have little response to a sea spectrum - although the small responses would be out of phase with the wave spectra. The approach taken was to use aircraft configurations which have floats with small waterplane areas and high moments of inertia; supporting an aircraft on three or four vertical floats was a popular technique. Experimental and theoretical studies[4] confirmed the validity of this approach, although design studies showed that incorporation of such flotation devices made a significant impact on the aircraft design and resulted in prohibitively high structural weights.

For unmanned seaplane applications this approach is impractical due to the small size of the vehicle (structures would have high natural frequencies, independent of configuration details). An alternative solution would be to design the unmanned seaplane to follow the wave contour. Motion amptitudes would be large but accelerations would not since motions would be in phase with the waves. This can be accomplished by designing the hull to have a large waterplane area and small moments of inertia. In this way the vehicle would display high natural frequencies (above the frequencies where most wave energy occurs) and all motions would be nearly in phase. Seaplane dynamics would be dominated by smooth accelerations; slamming would be minimized. Computer simulations have confirmed this concept[5]. Typical motions were found to be too severe for long term human habitation, but well within avionics and structural limits (Figure 5). Further research in more realistic environments are required before complete confidence in surface following can be achieved. Nonetheless, given the current data base, the ability of a small unmanned seaplane to loiter for long periods in rough water should not present a high risk technical challenge.

POSSIBLE UNMANNED SEAPLANE DESIGNS

Given the most realistic unmanned seaplane applications (Table 1), specific mission requirements for the seaplane can be defined (Table 2). Three conceptual unmanned seaplane designs were developed (Table 3, Figures 6-8) from these requirements. Each of these designs assumes land-basing and control from either an overhead aircraft or ground stations. A

technology freeze of 1985 is assumed with an initial operational capability in 1992-1994. Lower risk technical options were chosen to reduce overall development risk and cost in each design.

The smallest aircraft (Figure 6) was designed for electronic warfare and submarine surveillance payloads (Table 2) weighing approximately 720 lb (330 kg) and is propelled by a single ducted propeller driven by a 1000 hp (750 kW) turboprop engine. This arrangement yields exceptionally high static thrust (3670 lb, 16.3 kN) but limits the aircraft cruising velocity to 200 to 250 knots (100 to 125 m/s); for the design missions these speeds are adequate. High lift is generated by a relatively large wing (the wing loading is 30.5 lb/ft^2, 1.46 kN/m^2), conventional leading edge slats, and double slotted flaps.

Sponsons are used to provide lateral hydrostatic stability. These simple devices result in high hydrodynamic natural frequencies, and therefore, excellent seakeeping motions and loads. Similar devices were commonly used on early seaplanes (prior to World War II) but were eliminated in favor of wing tip floats because of their lower drag and weight. The rough water requirements of an unmanned seaplane make sponsons more attractive, although their advantages are yet to be fully demonstrated. The use of sponsons, however, is not critical to the unmanned seaplane concept but is indicative of the unorthodox configurations which might be practical for this application.

This small aircraft was designed to have a mission radius of 1600 n mi (2960 km) with a sea loiter endurance of 48 hours; at this radius the airborne endurance is 7.4 hours. Sufficient fuel is available for three 200 n mi (370 km) flights during the sea loiter period. The sea loiter endurance is limited by avionics reliability and power consumption.

A significantly larger unmanned seaplane (Figure 7) was designed for the high performance attack missions (ship attack and air warfare). This 25,400 lb (11,550 kg) aircraft can carry a 3200 lb (1450 kg) payload on a 1600 n mi (2960 km) radius mission with a 72.0 hour sea loiter endurance. Three 200 n mi (370 km) midmission flights can be performed during this period. A 4.6 hour airborne endurance is possible at the design mission radius. The installed thrust-to-weight ratio is 0.50; thrust is supplied by two high bypass ratio turbofans. These engines are housed high and forward on the wing to permit Upper Surface Blown (USB) flaps to be employed. The engine nacelles have a deflector in the rear to generate high lift over the USB flaps; this technique was developed on the USAF/Boeing YC-14 transport. The nacelle can be sealed to insure that salt crustation will not occur on turbofan components while sea loitering.

Lateral hydrodynamic stability is maintained with wing tip floats (Figure 7). These devices are locked in a horizontal position during airborne flight and high speed on-water maneuvers (e.g., takeoff and landing). During sea loitering periods, the floats are rotated to a vertical position. This configuration reduces lateral motions, particularly slamming, and loads. This technique, in essence, uses the vertical float approach to seakeeping for lateral motions. During ground operations, the tip floats would be partially rotated exposing outrigger landing gear. This particular float configuration has not been demonstrated but does not involve high risk and is not critical to the total concept.

The total aircraft has exceptional speed capability: a stall speed of 60 knots (30 m/s) and a maximum speed of 425 knots (210 m/s) at altitude.

The high installed thrust provides a rate of climb of 6700 ft/min (2040 m/min) at sea level; the aircraft can climb to 50,000 ft (15,200 m) in approximately 28 minutes (Table 3).

To minimize drag, the 3200 lb (1450 kg) payload is housed within the seaplane hull. Flotation requirements provide for ample volume. Weapons are ejected through a door aft of the hull step. This arrangement precludes a missile seeker lock-on prior to launch, thus an advanced missile seeker may be required for this application.

A very large unmanned seaplane was designed for anti-submarine and electronic warfare missions requiring only moderate speed but large payloads (Table 2). This design (Figure 8) weighs 34,800 lb (10,600 kg) and is capable of 1200 n mi (2200 km) radius missions with 72.0 hours on station (afloat); fuel is available for three 200 n mi (370 km) mid-mission flights. The aircraft is propelled by two conventional turboprop engines. High lift is generated by deflecting the propeller slipstream over double slotted flaps along the wing trailing edge. The aircraft has exceptional range payload performance when additional fuel is carried in two under wing drop tanks. With these tanks, the design mission radius can be doubled to 2400 n mi (4400 km). The additional fuel tanks must be dropped prior to landing on water; they can be particularly useful for operations where the water is too rough to land since the airborne endurance can be increased to 26.4 hours at 1200 n mi (2200 km). The large size and high thrust-to-weight ratio of this aircraft may permit operations in State 6 seas. This aircraft is designed to carry all its 5300 lb (2400 kg) payload within the hull. Torpedos would be stored in a bay aft of the hull step and ejected aftward. For submarine surveillance operations, a

retrievable sensor would be located in this area. The large hull also provides ample volume and surface area for large antenna.

Lateral hydrodynamic stability is provided with rotatable wing tips which serve as floats when rotated (Figure 8); this arrangement allows for lateral flotation and reduced lateral structural span. The wing tips would have a small waterplane area. As with the other configurations presented, this technique is unorthodox but does not represent high risk and is not critical to the concept.

These configurations were based on manned seaplane experience which may not be best for this application. More radical configurations, such as in Figure 9, may have substantially better performance, reliability, and/or lower cost. Further configuration and subsystem integration studies are needed to determine the full potential of this concept.

POTENTIAL SAVINGS

The potential savings in fuel, capital, and manpower possible using unmanned seaplanes are presented for three simple scenarios in Table 4. In Table 4a, resource requirements for an undersea surveillance mission are presented for two approaches with equivalent effectiveness: a land-based P-3 aircraft intermittently interrogating a disposable sensor, and an unmanned seaplane continuously on station relaying data via satellite to a ground station. The seaplane is based on the design shown in Figure 8. A 96 percent reduction in fuel and 62 percent reduction in total acquisition costs result with its use. The need for aircraft flight crews is completely eliminated.

In barriers operations (Table 4b) the unmanned seaplane can provide similar savings when compared against surface ships. In this case, a fleet of high and moderate performance unmanned seaplanes (Figures 7 and 8) are deployed with a single P-3 aircraft continuously providing command, control, and air surveillance (this is a conceptual P-3 derivative). The unmanned seaplanes with the P-3 can reduce manpower requirements by 45 percent, fuel requirements by 58 percent, and total acquisition costs by 85 percent. Increased operational flexibility is derived by the high speed in which the unmanned seaplanes and P-3 aircraft can be deployed and repositioned.

In a convoy escort role (Table 4c), savings are also possible. A variety of small and large unmanned seaplanes (Figures 6, 7 and 8) would be required with an overhead P-3. Compared to an all P-3 force, a savings of 27 percent in manpower (almost all in flight personnel), 73 percent in fuel, and 50 percent in total acquisition costs could be possible. In these operations, the small unmanned seaplanes (Figure 6) could be controlled by ship-board personnel via a secure data link. The P-3 would control the more remote and complex seaplanes.

In summary, a substantial savings can result from the use of unmanned seaplanes for naval missions. However, these savings can only be realized if rough water operations can be routinely conducted and if minimal real-time control is required. Also, the acquisition costs of these vehicles must be kept low; thus high risk technical options must be avoided.

CONCLUDING REMARKS

The unmanned seaplane offers substantial savings in manpower, capital, and fuel. However, in order to realize this potential several critical technical issues must be resolved; these include the ability to operate in rough water, and the development of a practical control system. The current technology base provides some confidence that these issues can be resolved and that the development of unmanned seaplanes is possible with moderate risk. Further research and development, however, is required in order to permit an accurate assessment of the ultimate potential of this concept.

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TABLE 1 - POTENTIAL UNMANNED SEAPLANE APPLICATIONS

Electronic Warfare and Support
Submarine Surveillance
Ship Identification
Ship Attack
Submarine Contact Investigation
Aircraft Attack

TABLE 2 - CONCEPTUAL UNMANNED SEAPLANE MISSION REQUIREMENTS

MISSION	PAYLOAD WEIGHT (lb)	MISSION RADIUS (n mi)	DASH SPEED (knots)	RATE OF CLIMB (ft/min at sea level)	SERVICE CEILING (ft)
Electronic Warfare	500	1200-1600	NC	NC	20,000+
	4000-6000	1200-1600	NC	NC	20,000+
Submarine Surveillance	5000	1200	NC	NC	NC
Ship Identification	500	1200-1600	250+	2000+	20,000+
Ship Attack	3000	1200-1600	400+	5000+	30,000+
Submarine Contact Investigation	500	1600	200+	NC	NC
	5000	1200-1600	300+	5000+	NC
Aircraft Attack	3000	1600	400+	5000+	50,000+

TABLE 3 - CONCEPTUAL UNMANNED SEAPLANE CHARACTERISTICS

Gross Weight (lb)	7300	25,400	34,800
Empty Weight (lb)	2840	10,140	17,760
Payload Weight (lb)	720	3200	5300
Propulsion System	Single Ducted Prop (1000 hp)	Two 8500 lb Turbofans	Two 4200 hp Turboprops
Design Mission Radius (n mi)	1600	1600	1200
Design Sea Loiter Endurance (h)	48	48	72
Maximum Airborne Endurance (h)	30.2	13.7	23.4
Maximum Operating Sea State	5	5	6
Sea Level Rate-of-Climb (ft/min)	2400	6700	5800
Service Ceiling (ft)	25,000	58,000	38,000
Cruise Speed (knots)	200-250	400-430	300-340
Stall Speed (knots)	60	60	60
Onboard Power Generation Capacity, while afloat (kW)	5	50	100

TABLE 4 - POTENTIAL SAVINGS WITH UNMANNED SEAPLANES

(a) Undersea Surveillance Mission*

Aircraft on Station	1 P-3**	1 Unmanned Seaplane***
Sortie Rate (per day)	2	1/3
Total Aircraft Required	2 P-3	3 Unmanned Seaplanes
Flight Crews Required	3	0
Total Manpower Required	126	90
Daily Fuel Required (lb)	118,000	4800

Notes: *Area 1200 n mi from base
**P-3 not on station continuously
***Unmanned seaplane with submarine surveillance payload; on station continuously.

TABLE 4 - POTENTIAL SAVINGS WITH UNMANNED SEAPLANES

(b) Short Term Barrier Against All Threats*

Forces On Station	1 DDG-47 1 DD-963 1 FFG-7	1 P-3** 5 Unmanned Seaplanes***
Total Forces Required	1 DDG-47 1 DD-963 1 FFG-7	4 P-3 12 Unmanned Seaplanes
Total Manpower Required	742	408
Daily Fuel Required (lb)	633,600	264,000
Total Acquisition Cost ($M,1979)	1450	224

Notes:

*Short term barrier, 50 x 200 n mi; 1200 n mi from base

**P-3 is a conceptual design capable of AEW/C and is on station continuously

***Unmanned seaplanes carry air, submarine, surface, and electronic warfare payloads (Figures 7 & 8)

TABLE 4 - POTENTIAL SAVINGS WITH UNMANNED SEAPLANES

(c) Convoy Escort Against Submarine and Surface Threats

Aircraft on Station	4 P-3	1 P-3* 5 Unmanned Seaplanes**
Total Aircraft Required	16 P-3	4 P-3 12 Unmanned Seaplanes
Flight Crews Required	20	5
Total Manpower Required	560	410
Daily Fuel Required (lb)	1,267,000	336,000
Total Acquisition Cost ($M,1979)	512	256

Notes: *P-3 is a conceptual design capable of AEW/C^3 and is on station continuously.
**Unmanned seaplanes carry submarine surveillance, contact investigation, ship identification, ship attack, and electronic warfare payloads (Figures 7 and 8).

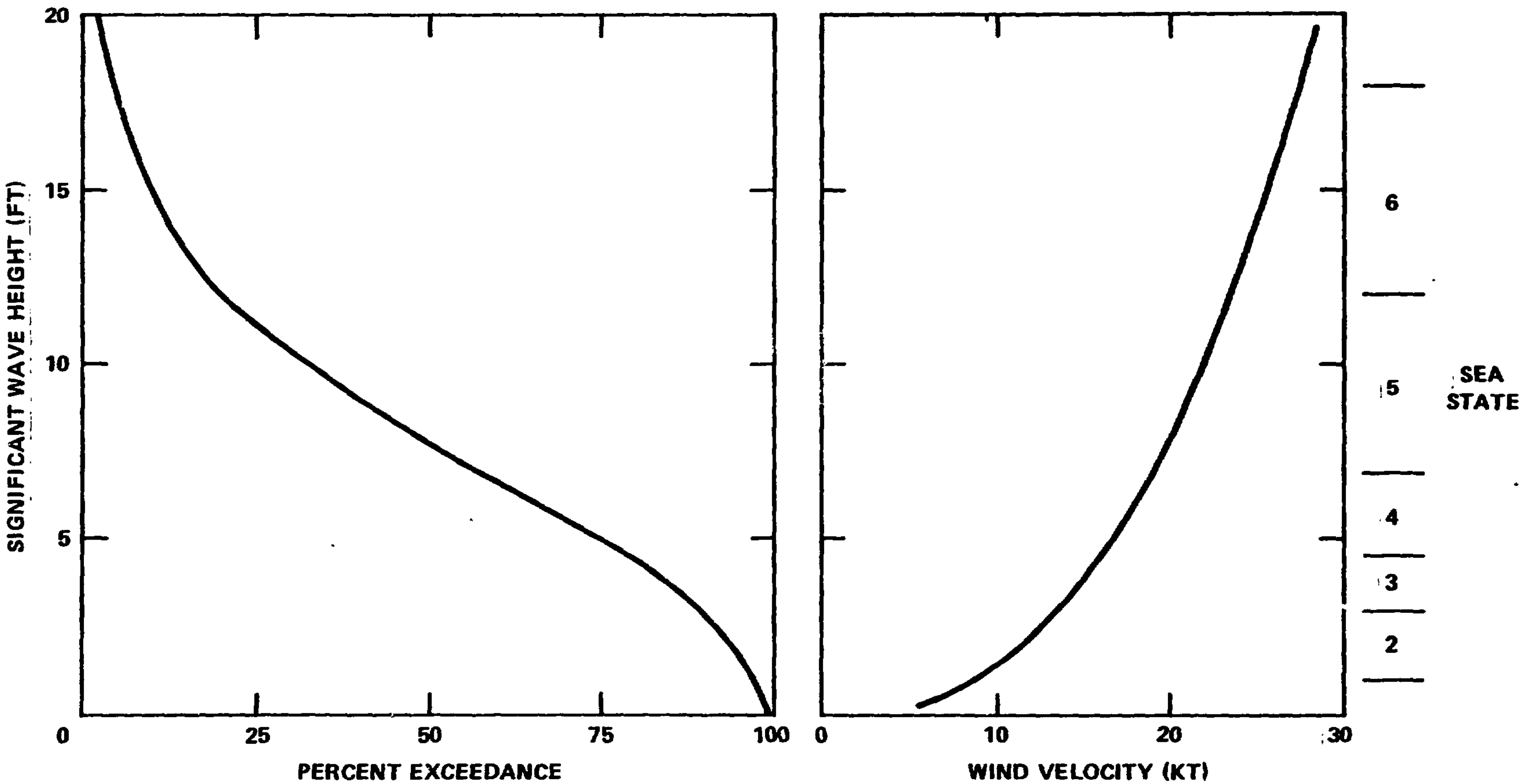


Figure 1 - Sea State Statistics

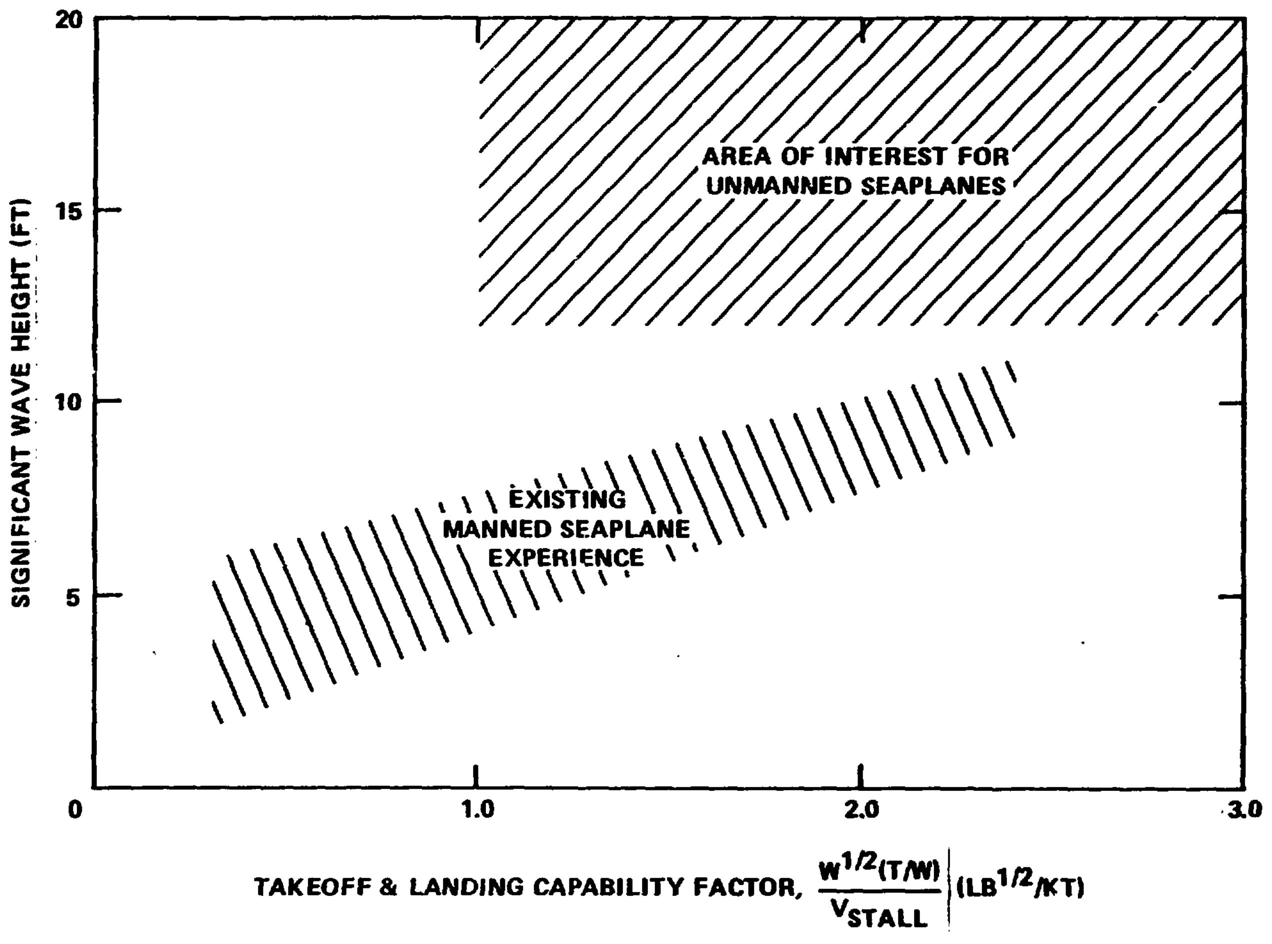


Figure 2 - Seaplane Capabilities in Rough Water

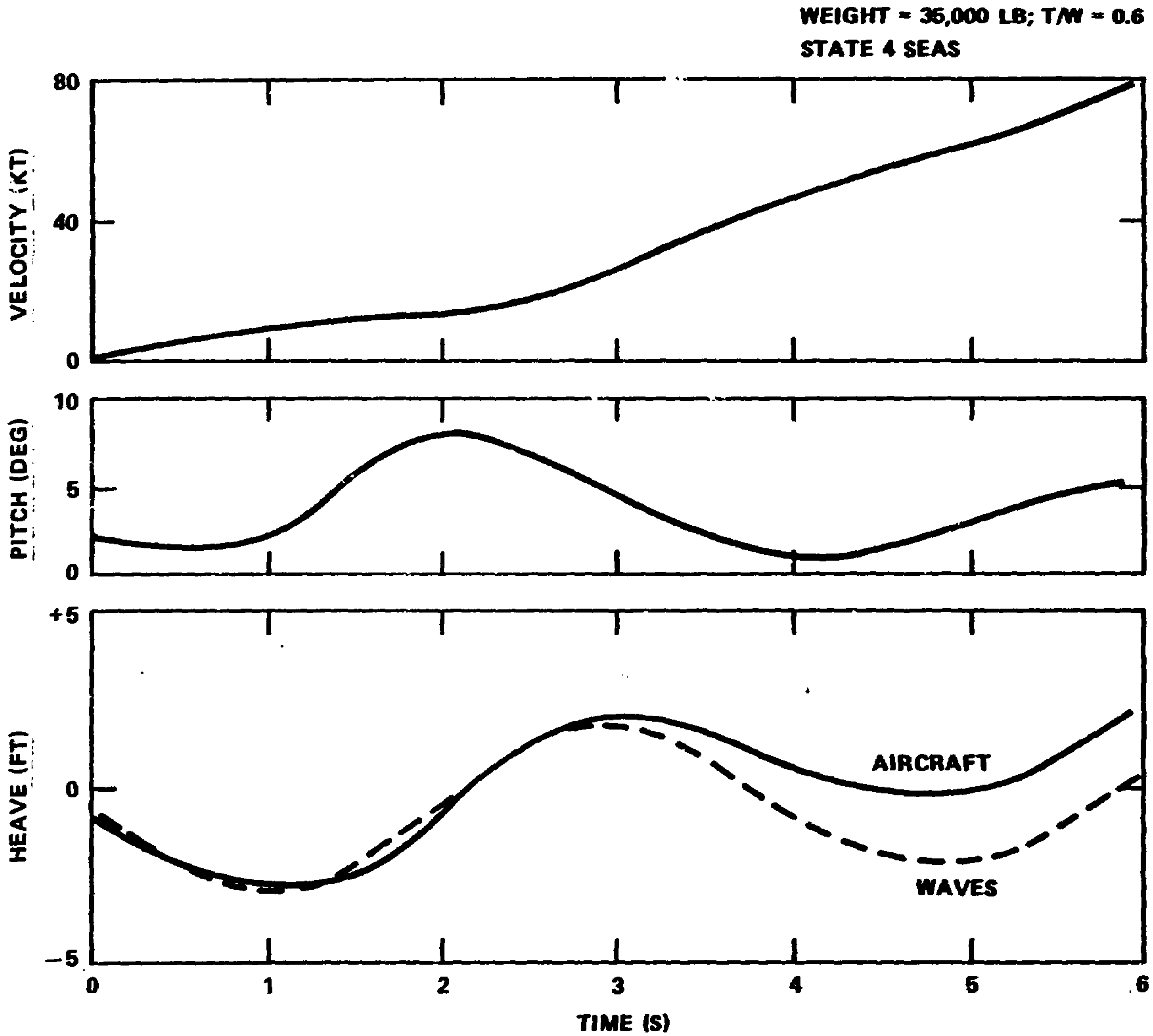


Figure 3 - Seaplane Planing-Off Dynamics

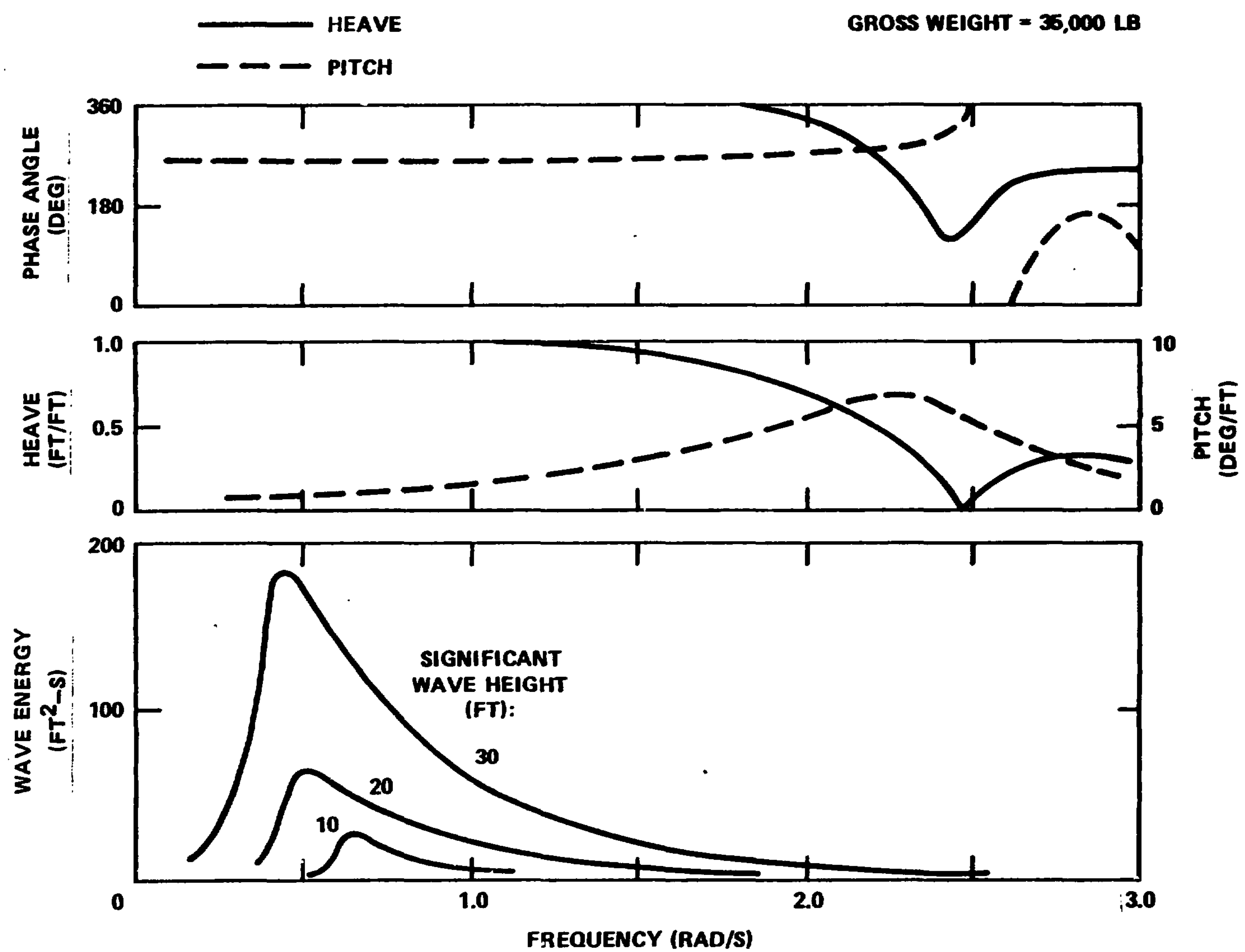


Figure 4 - Seaplane Responses in a Seaway

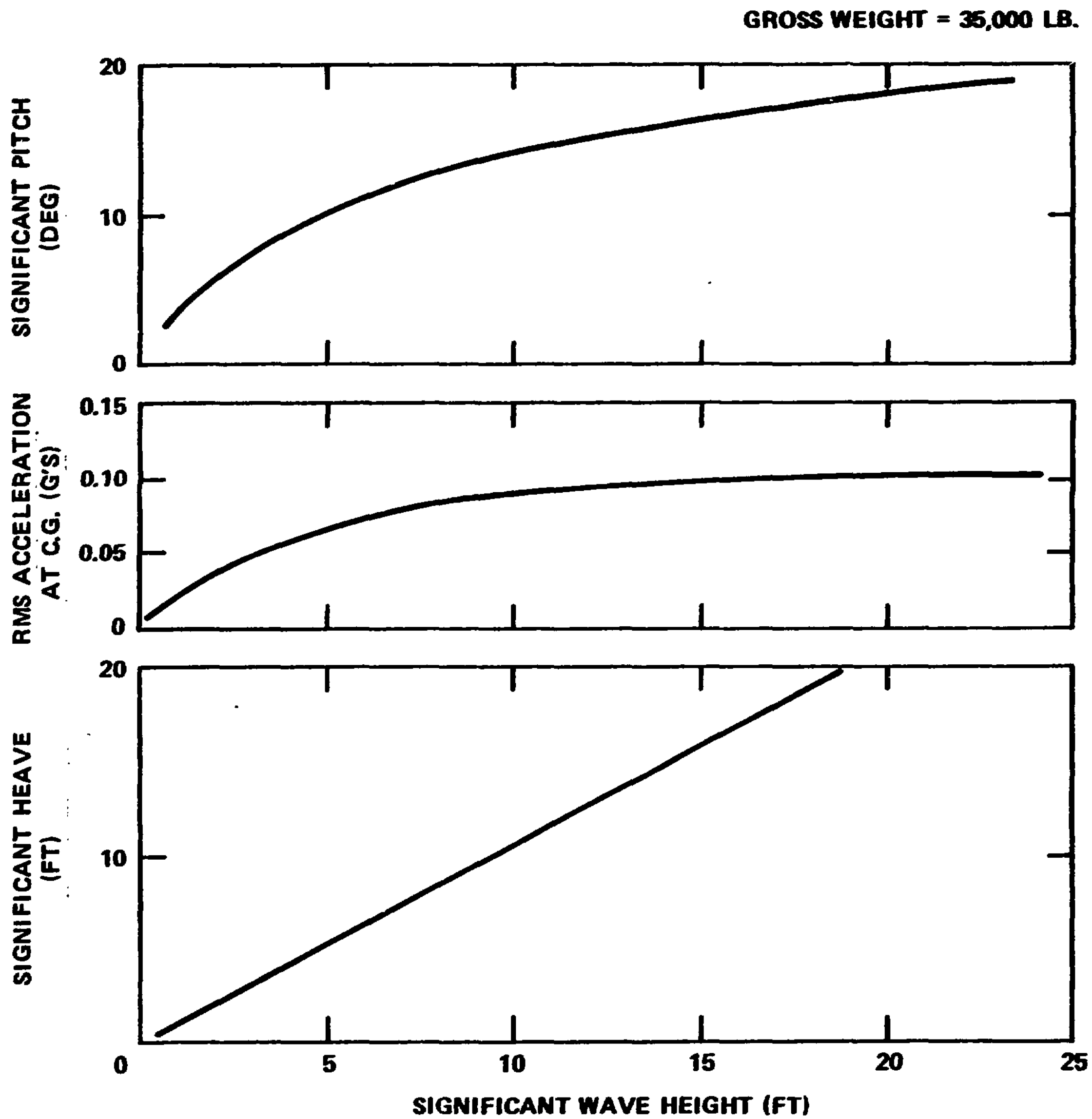


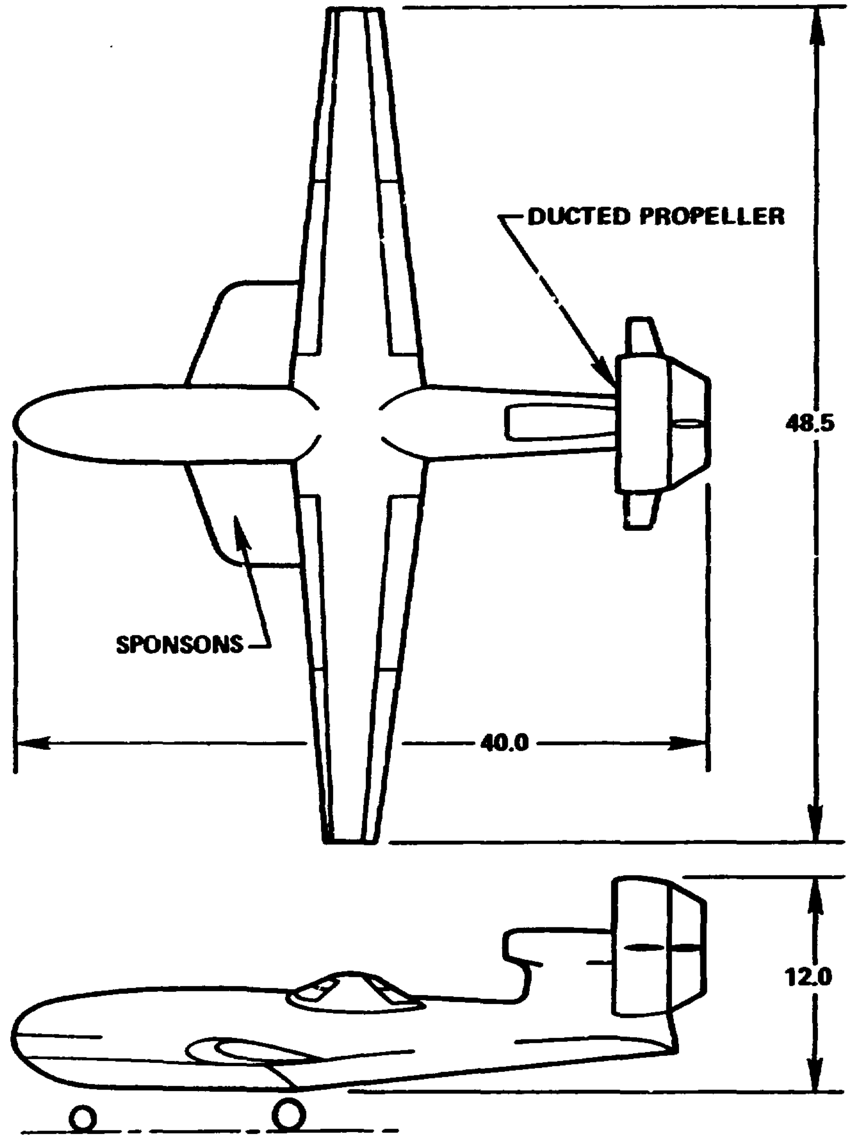
Figure 5 - Sea Loitering Dynamics

CHARACTERISTICS

GROSS WEIGHT	7300 LB
EMPTY WEIGHT	2840 LB
PAYLOAD WEIGHT	720 LB
WING LOADING	30.5 LB/FT^2
HULL L/B	8.4
INSTALLED POWER	1000 HP
DESIGN RADIUS	1600 NMI
DESIGN ENDURANCE	48 H

APPLICATIONS

ELECTRONIC WARFARE
SUBMARINE WARFARE



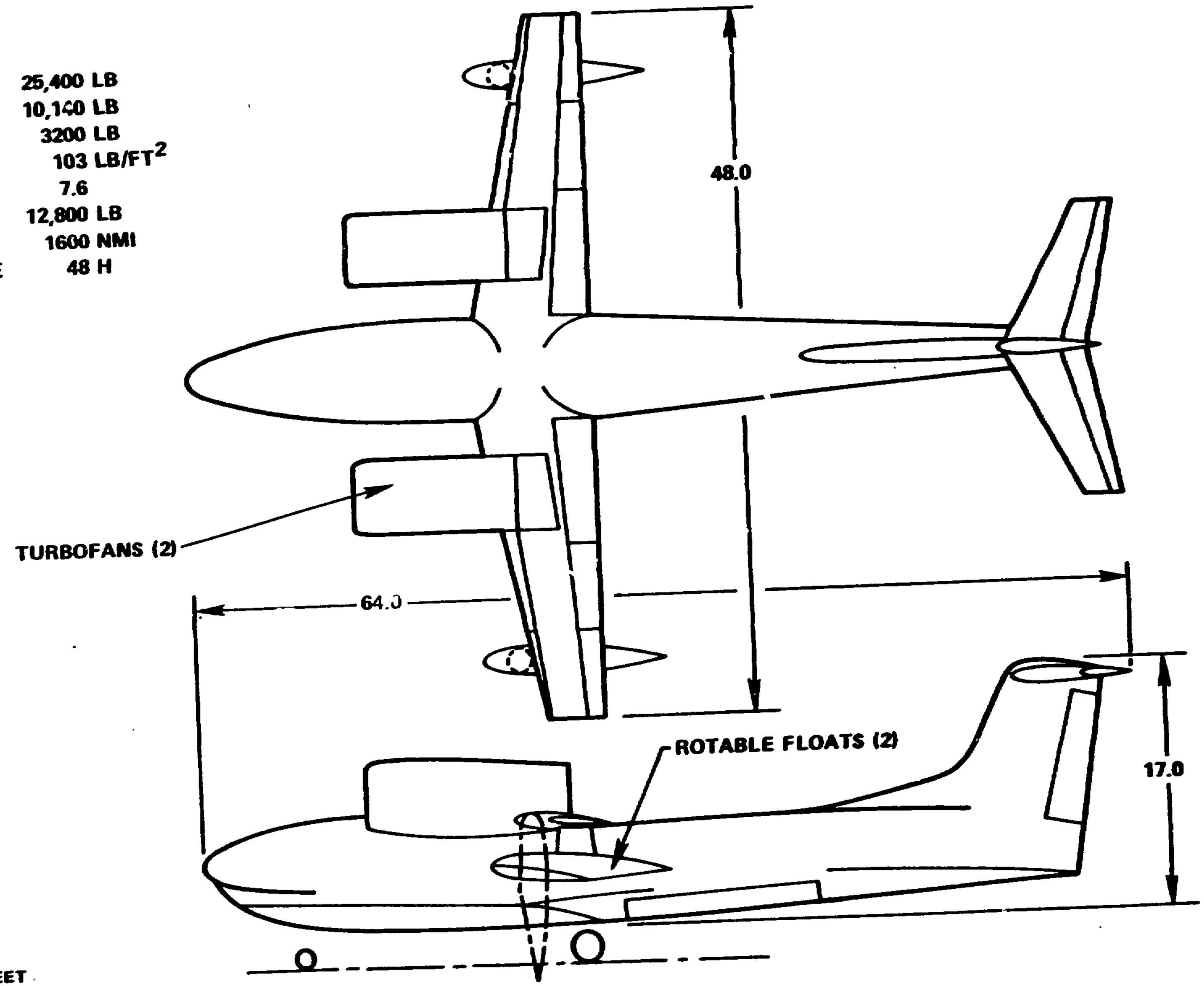
ALL DIMENSIONS IN FEET

Figure 6 - Small Unmanned Seaplane

CHARACTERISTICS	
GROSS WEIGHT	25,400 LB
EMPTY WEIGHT	10,140 LB
PAYLOAD WEIGHT	3200 LB
WING LOADING	103 LB/FT^2
HULL L/B	7.6
INSTALLED THRUST	12,800 LB
DESIGN RADIUS	1600 NMI
DESIGN ENDURANCE	48 H

APPLICATIONS

SURFACE WARFARE
AIR WARFARE



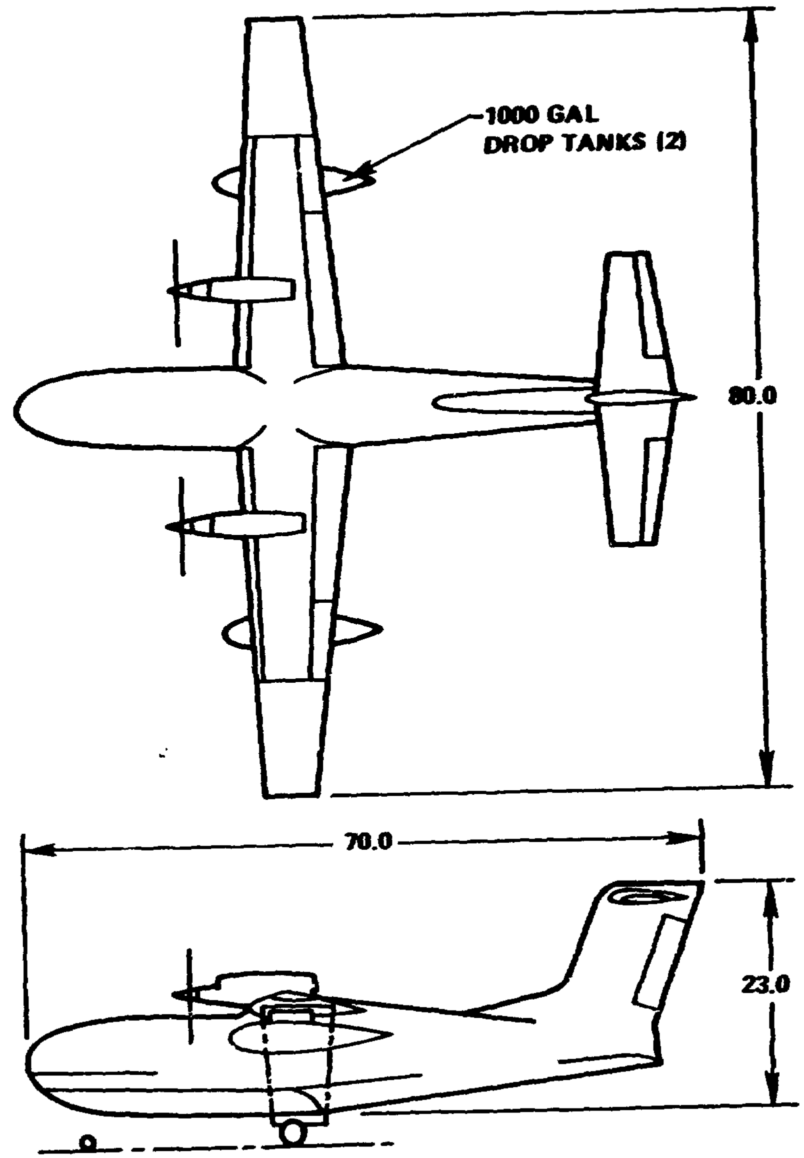
ALL DIMENSIONS IN FEET

Figure 7 – High Performance Unmanned Seaplane

CHARACTERISTICS	
GROSS WEIGHT	34,800 LB
OVERLOAD WEIGHT	48,000 LB
EMPTY WEIGHT	17,760 LB
PAYLOAD WEIGHT	5300 LB
WING LOADING	54.4 LB/FT^2
HULL L/B	8.0
INSTALLED POWER	8400 HP
DESIGN RADIUS	1200 NMI
DESIGN ENDURANCE	72 H

APPLICATIONS

SUBMARINE WARFARE
ELECTRONIC WARFARE

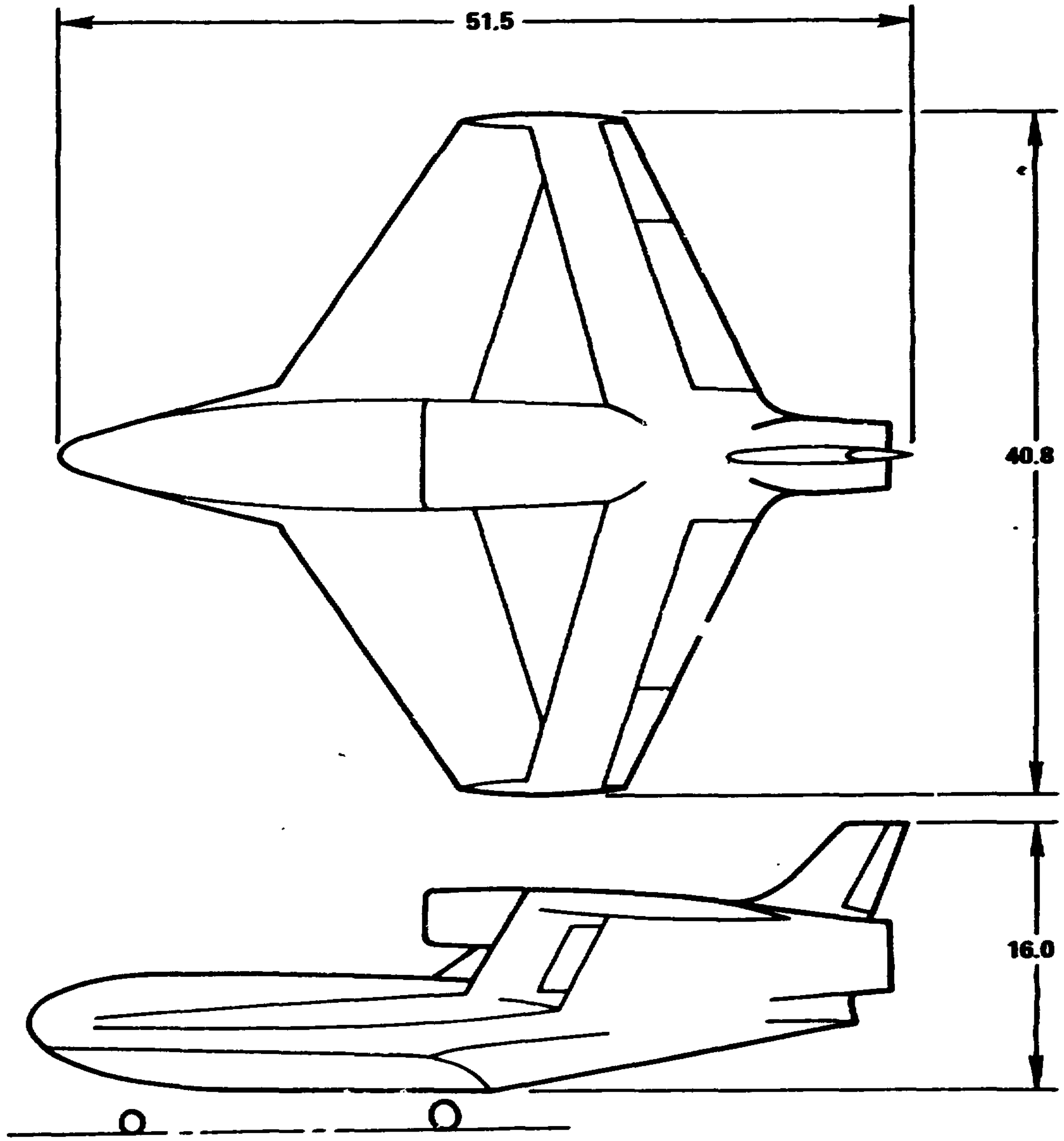


ALL DIMENSIONS IN FEET

Figure 8 - Large Unmanned Seaplane

CHARACT .STICS

GROSS WEIGHT	20,000 LB
PAYLOAD WEIGHT	2500 LB
DESIGN RADIUS	1600 NMI
DESIGN ENDURA.ICE	120 H



ALL DIMENSIONS IN FEET

Figure 9 - Advanced Unmanned Seaplane

UNMANNED SYSTEMS FOR REDUCING OUR TAXES

by

Gerald R. Seemann, PhD, P.E.
Developmental Sciences, Inc.

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Introduction:

In the decade of the 1980's, it is predicted that unmanned vehicles systems will be in operation around the globe, performing a wide range of civilian activities. The driving forces that will bring this prediction to fruition will be economics, technology transfer, and safety considerations. The many civilian applications are derived from the need of many state, county and local governmental agencies for surveillance/information gathering systems. Cost effectiveness is a primary concern for these institutions.

Unmanned vehicle systems potentially offer a low cost alternative to the helicopter and fixed wing aircraft for a broad spectrum of civilian functions primarily thru the reduction of labor costs. In reference 1 a number of civilian RPV's concepts were discussed. This paper presents three candidate unmanned vehicle systems for consideration to perform these non military missions. The three vehicle systems chosen for presentation are;

- H-UVS - a skirted hovercraft unmanned vehicle system
- FWM-UVS - a fixed wing mini-class unmanned vehicle system
- LTA-UVS - a lighter-than-air unmanned vehicle system

Each unmanned vehicle system will be discussed in terms of application, configuration, performance, payloads and costs. In each case a vehicle system and a ground station are required.

CANDIDATE SYSTEMS

- H-UVS

Introduction:

A hybrid hovercraft UVS that could traverse liquids, climb over certain ground obstacles, be relatively corrosion proof and hazard free could be very useful for the general class of hazardous materials. In recent years hazardous material spills have occurred with increasing frequency, with resultant loss of life (tens of), injuries (thousands of), and major property damage (hundreds of millions), and the situation is expected to worsen.[2,3] These spills occur from mobile (rail and highway) as well as stationary (tanks and reactors) sources. In all cases, information is needed immediately as the danger to humans is often high or lethal, (one dramatic demonstration of this need was the Three Mile Island Reactor incident.) Therefore an unmanned system which could safely penetrate the hazardous area and gather information via sensors would become a cost effective tool for disaster management.

Mission and Description

Work began on a non-nuclear system for EPA in late 1977, the background of which is found in reference 4. In the general mission scenario the H-UVS would be brought to within a mile or less of the sight dependent on many factors. The typical H-UVS would have an imaging system, e.g. a low light level video system with pan, tilt and zoom capability and gas and liquid sensing units. The operator would start the engine, quickly check all functions (go/no go type) and remotely drive the

H-UVS to the area of interest. An artist conception of an H-UVS nicknamed "Spill Patrol" is shown in Figure 1, exploring a derailed freight train. With the on board sensors, the command post operator could establish "first hand" the nature of the problem, the type of gas or liquid that has been released and the possibility of trapped citizens. With this data either mitigating measures would be ordered and/or the local population would be evacuated.

While all-terrain vehicles and flying unmanned vehicles were considered, a skirted hovercraft vehicle was selected because of its ability to clear obstacles (a function of skirt dimension) and its amphibious nature. A prototype vehicle has been designed based on the following desired performance characteristics.

Maximum velocity	10 feet per sec.
Maximum grade capability	20 degrees
Maximum crosswind (at forward velocity of 4 fps)	25 knots
Maximum obstacle height	18 inches
Range (from command post)	1/2 mile
Endurance (with new batteries at maximum power consumption)	1 1/2 hours
Turning circle diameter	0*

The origin of these desired parameters are discussed in more detail in Reference 5.

*The vehicle can rotate, in place, about its own axis.

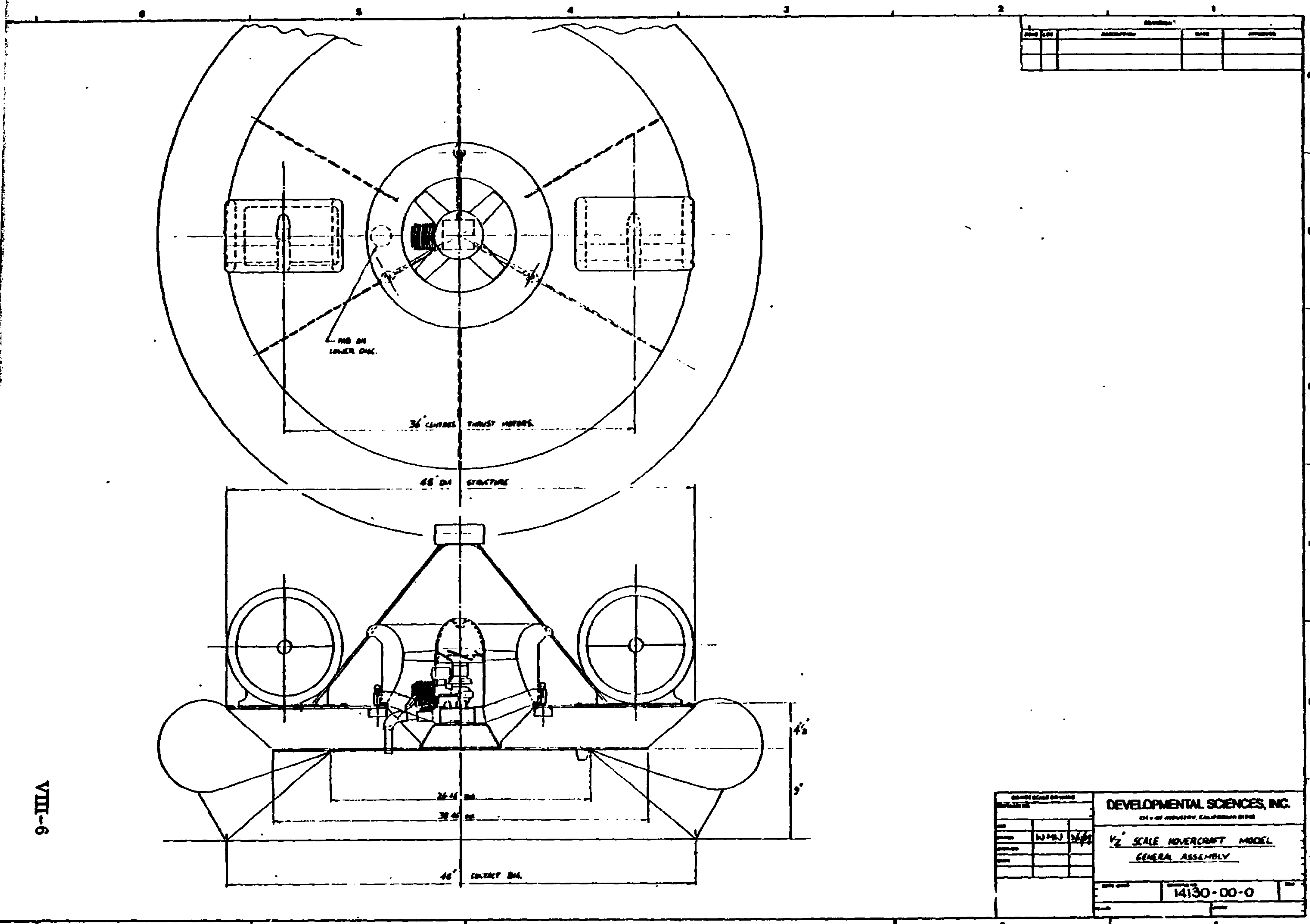
FIGURE (1)

The H-UVS configuration is shown in Figure 2. Size is restricted to a 8 feet diameter for transport reasons. A weight breakdown for this configuration is;

Weight breakdown:

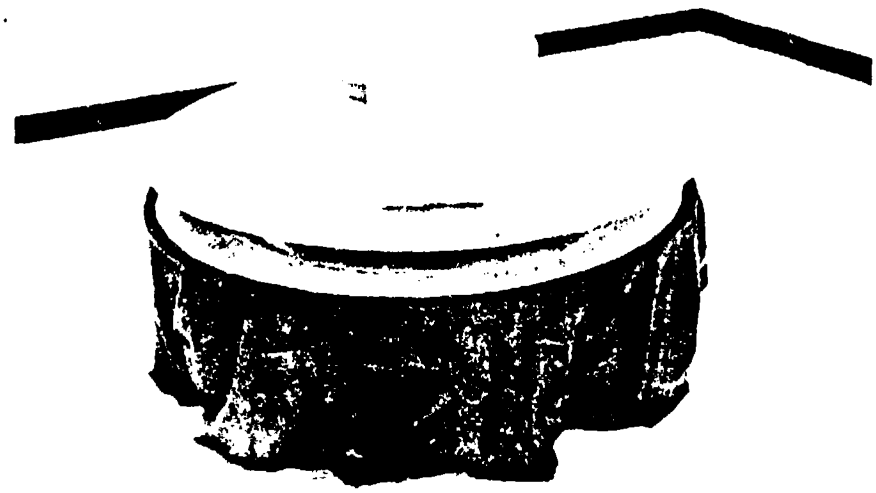
Structure	72 lbs.
Batteries (14,400 watts @ 260 watts/lb)	55 lbs.
Lift motor	6 lbs.
Lift fan	11 lbs.
Thrust motors	12 lbs.
Thrust rotors (incl. pitch mechanisms)	24 lbs.
Skirt and cushion bag	40 lbs.
Stabilized platform (incl. camera, velocity sensors and servos)	28 lbs.
Receiver/transmitter/antennae	8 lbs.
Auto pilot & wire harness	10 lbs.
Gas sensors/samplers	20 lbs.
Miscellaneous	14 lbs.
TOTAL	300 lbs.

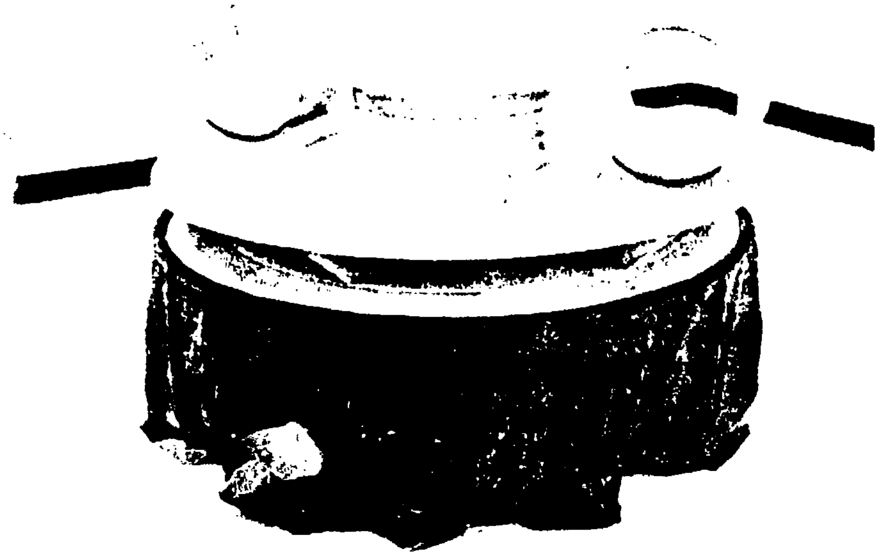
The vehicle subsystems are propulsion (including lift and thrust motors), auto-pilot, data links, sensors (including TV system and gas sensors/samplers), spotlights and audio. The design has been guided by the fact that neither the vehicle as a whole or any of its subsystems can accentuate the existing hazard. An electric propulsion system using high energy density lithium thionyl chloride batteries has been proposed. A preprototype test vehicle is shown in Figure 3.



PAD ON LOWER DISC.
36" CENTRES THRUST MOTORS.
46" DIA STRUCTURE
4½"
9"
26 46" DIA
38 46" DIA
46" CONTACT DIA.
DEVELOPMENTAL SCIENCES, INC.
CITY OF INDUSTRY, CALIFORNIA
WMJ
½" SCALE HOVERCRAFT MODEL
GENERAL ASSEMBLY
14130-00-0

FIGURE (2)





PROTOTYPE HOVERCRAFT
UNDER CONSTRUCTION

FIGURE (3)

- System Discussion

Presently there exists no alternative for comparison purposes. Although a system/cost effectiveness is difficult to assess at this point in the development, the H-UVS could provide a unique capability, one that once implemented could save lives (those of responding personnel) and reduce property losses, (commander can develop and implement strategy more rapidly.) It is believed that the sub system technology will improve on all fronts during the next decade due to DOD and DOE programs, which will reduce costs even further.

After development costs an H-UVS plus control console in reasonable production should cost under $90,000.00. Maintenance and mission costs can only be estimated but for a normal, "non-catastrophic lifetime," a mission cost of $1500 - $3000 seems probable, excluding development costs.

The deployment of H-UVS strategically throughout the nation could be a positive response to a growing-serious problem.

- FWM-UVS

Introduction:

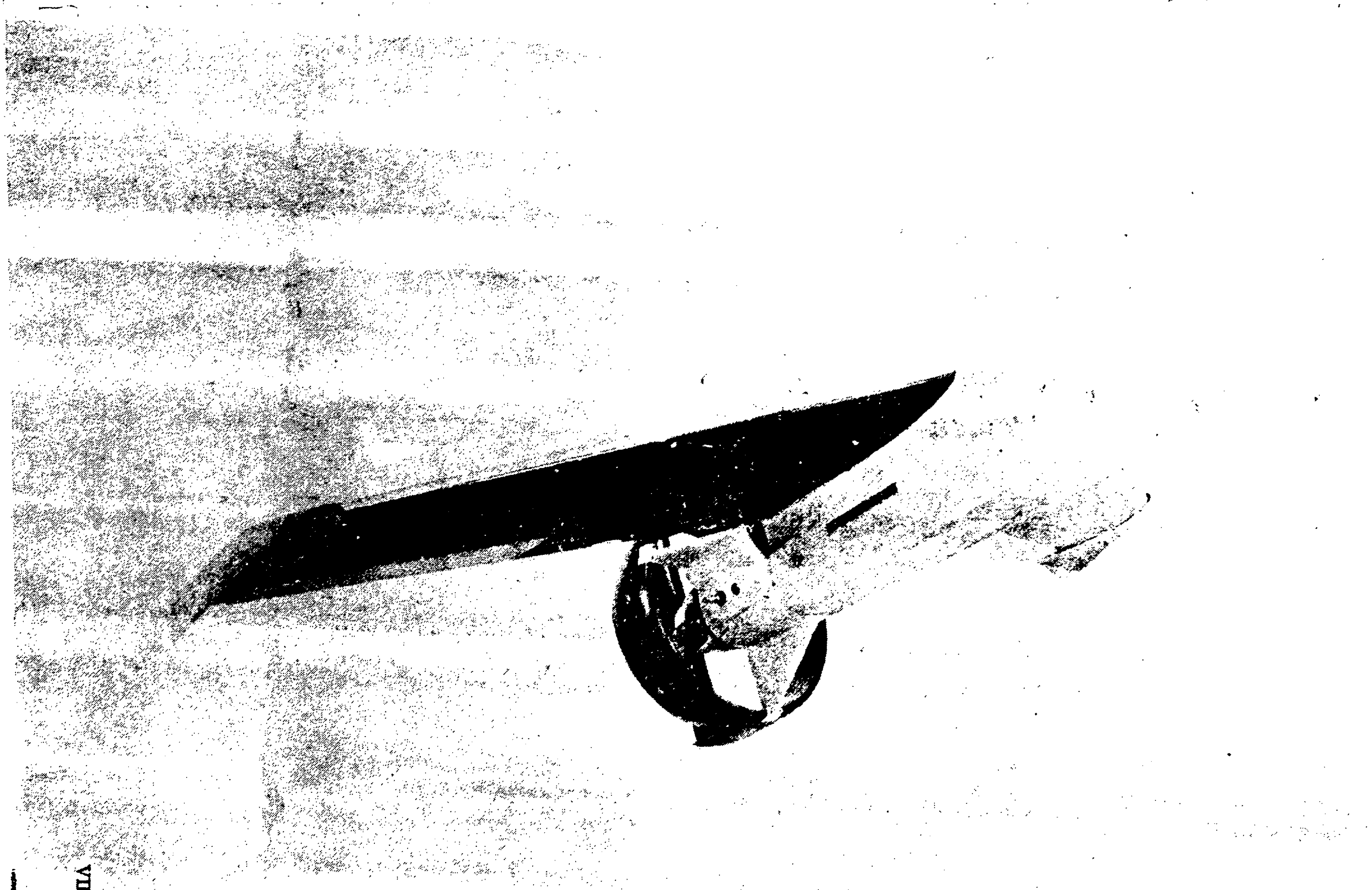
A fixed wing mini-unmanned vehicle in the 200 - 300 lb. class will find a variety of civilian uses some of which will overlap with the LTA-UVS. Due to current FAA regulations and safety reasons (such as the question of collision avoidance) the FWM-UVS will not be used in urban areas. The advantages of the FWM-UVS over the LTA-UVS are top speed and maneuverability. Applications for the FWM class of unmanned vehicle systems include pipeline and powerline surveillance and monitoring (linear patrol), land development and mapping studies, fishing fleet spotting, agricultural spraying, forest surveillance, and

aerodynamic and environmental research, for example. This class of UVS has considerable military interest, therefore civilian applications will benefit from its expanding technology base.[6] For routine surveillance and monitoring missions requiring speed (greater than 50 kts), altitude variations and maneuverabilty the FWM-UVS systems should provide a cost effective means for accomplishing these tasks, as long as only a single ground station is needed.

System Description

Recent work on fixed wing mini-unmanned vehicle systems began in the early 1970's under DARPA sponsorship. The U.S. Army continued the program thru the balance of this decade via the AQUILA program. For purposes of discussion the DSI SKY-EYE R-4D fixed wing system has been chosen to represent this class of FWM-UVS.

The SKY-EYE R-4D shown in Figure 4, is a swept wing configuration of 12 foot span with a gross of weight between 180 and 240 lbs. The airframe is light weight and rugged being of Kevlar/honeycomb construction. The propulsion system consists of a nominal 20 hp, 2 stroke I.C. engine which drives a ducted propellor and an alternator. Up to 1 kw of 28 vdc power can be available for payload needs. An automatic flight control system provides the necessary vehicle house keeping functions as well as controls for the payload. The vehicle can be controlled via the ground station or preprogrammed for particular missions. The SKY-EYE can carry up to 120 lbs. of fuel/payload. Two wing fuel bladders carry 30 lbs. of fuel although an auxilary fuselage fuel tank can be added if greater endurance or higher speed patrol is desired.



SKY EYE R4-D

FIGURE (4)

Performance numbers for the SKY-EYE R-4D are;

Top Speed (@5000') -	125 kts.
Max. endurance speed -	62 kts.
Stall Speed -	39 kts.
Max. endurance - (30 lbs. of fuel)	7 hours
Altitude Ceiling -	15,000 ft.

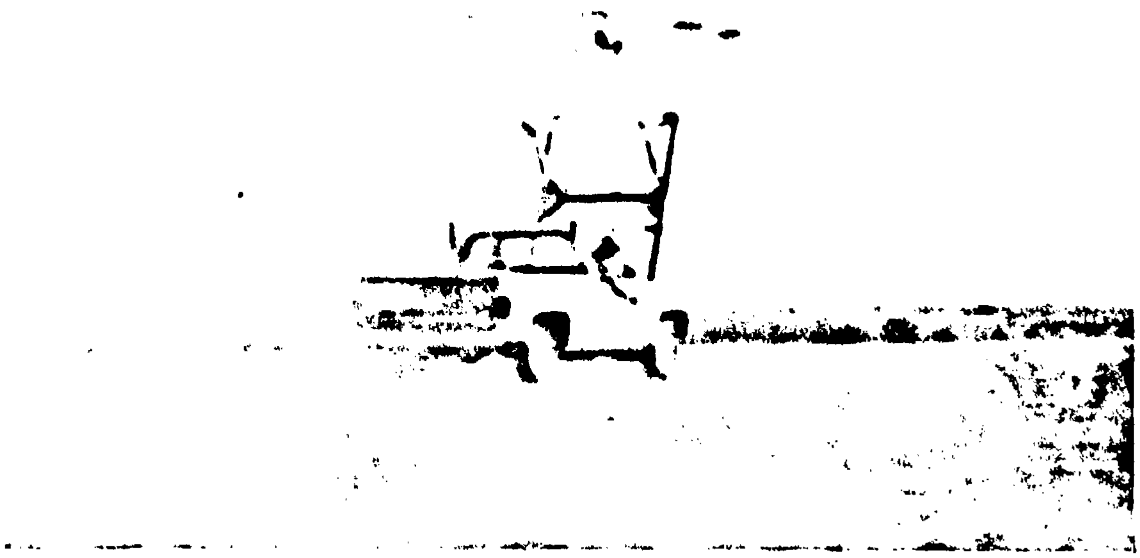
For safety reasons a parachute system will be most probably required for emergency situations.

Many launch and recovery options are available and final selection for civilian use will depend on several factors. A landing gear system is the least expensive although a good ground pilot is required and performance is compromised unless the gear is retractable. Truck or pneumatic launch have both been successfully demonstrated and an automatic net recovery provides a lower skill requirement option for civilian applications. Figures 5 & 6 show examples.

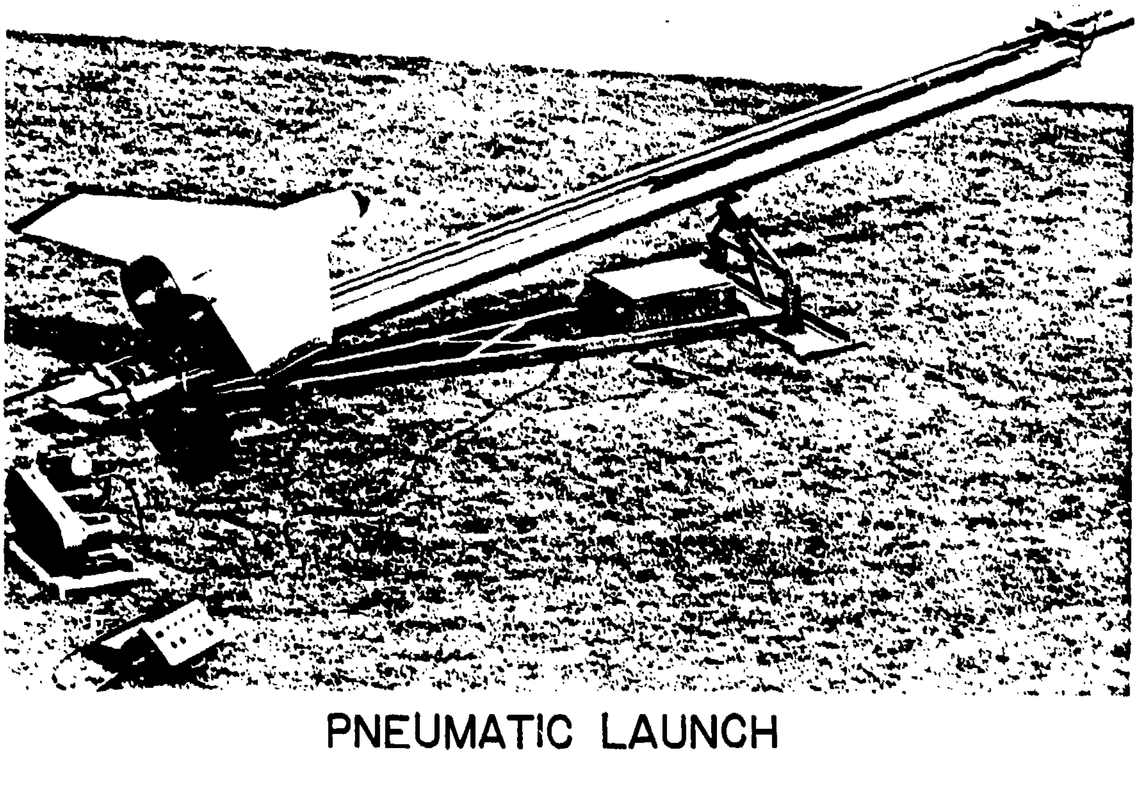
A ground station including a control console, tracking system and data display will be an important part of the system. Figure 7 shows some typical hardware used to control the system from the ground.

System Discussion

A typical scenario for a linear patrol mission, could be as follows. The FWM-UVS equipped with a video and photographic system is prechecked, flight plan programmed into the AFCS memory and the vehicle then mounted on the launcher. After fueling and final checkout, with all systems go, the FWM is launched, climbing to its specified heading and altitude. In this case the vehicle patrols



TRUCK LAUNCH



PNEUMATIC LAUNCH

FIGURE (5)

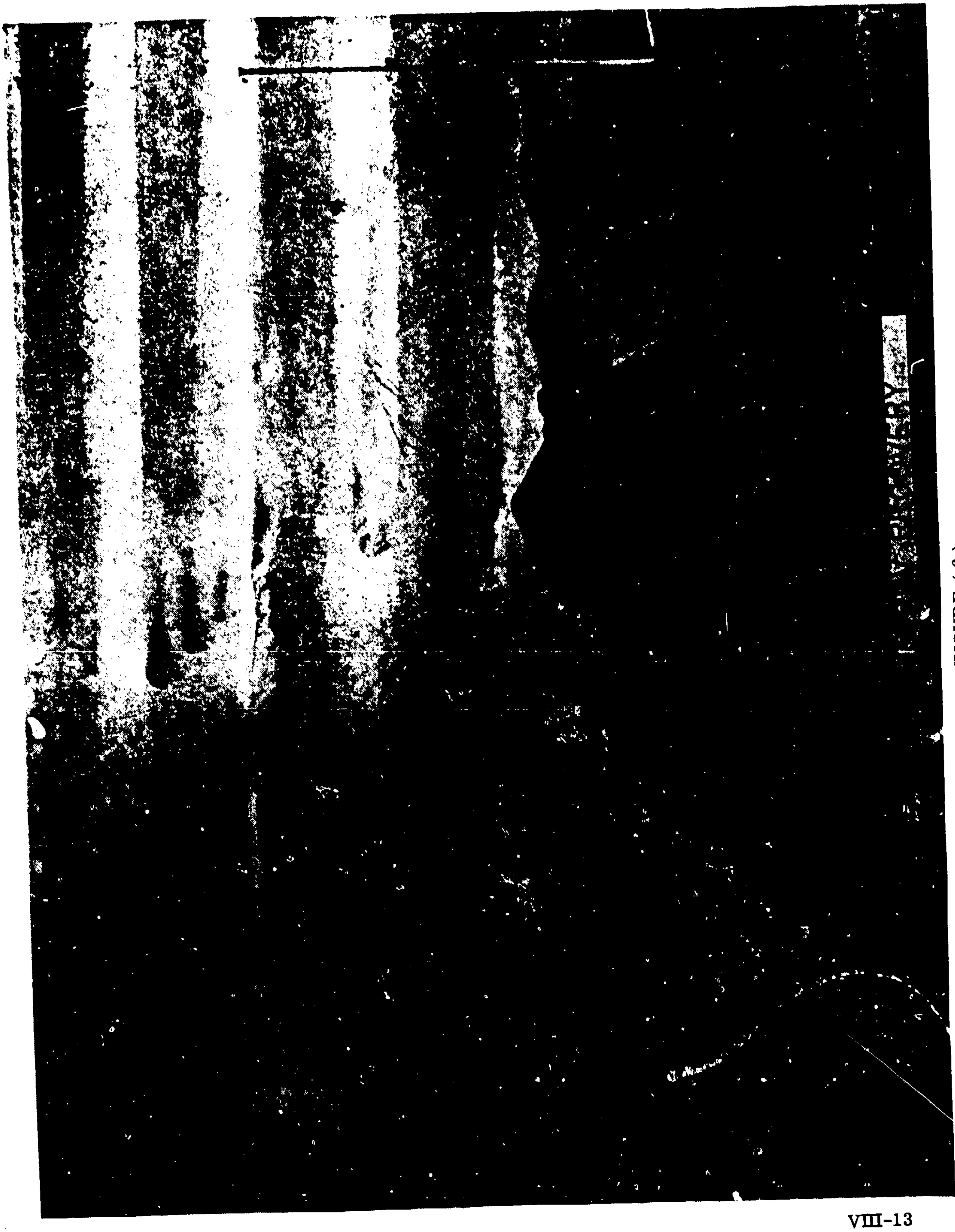
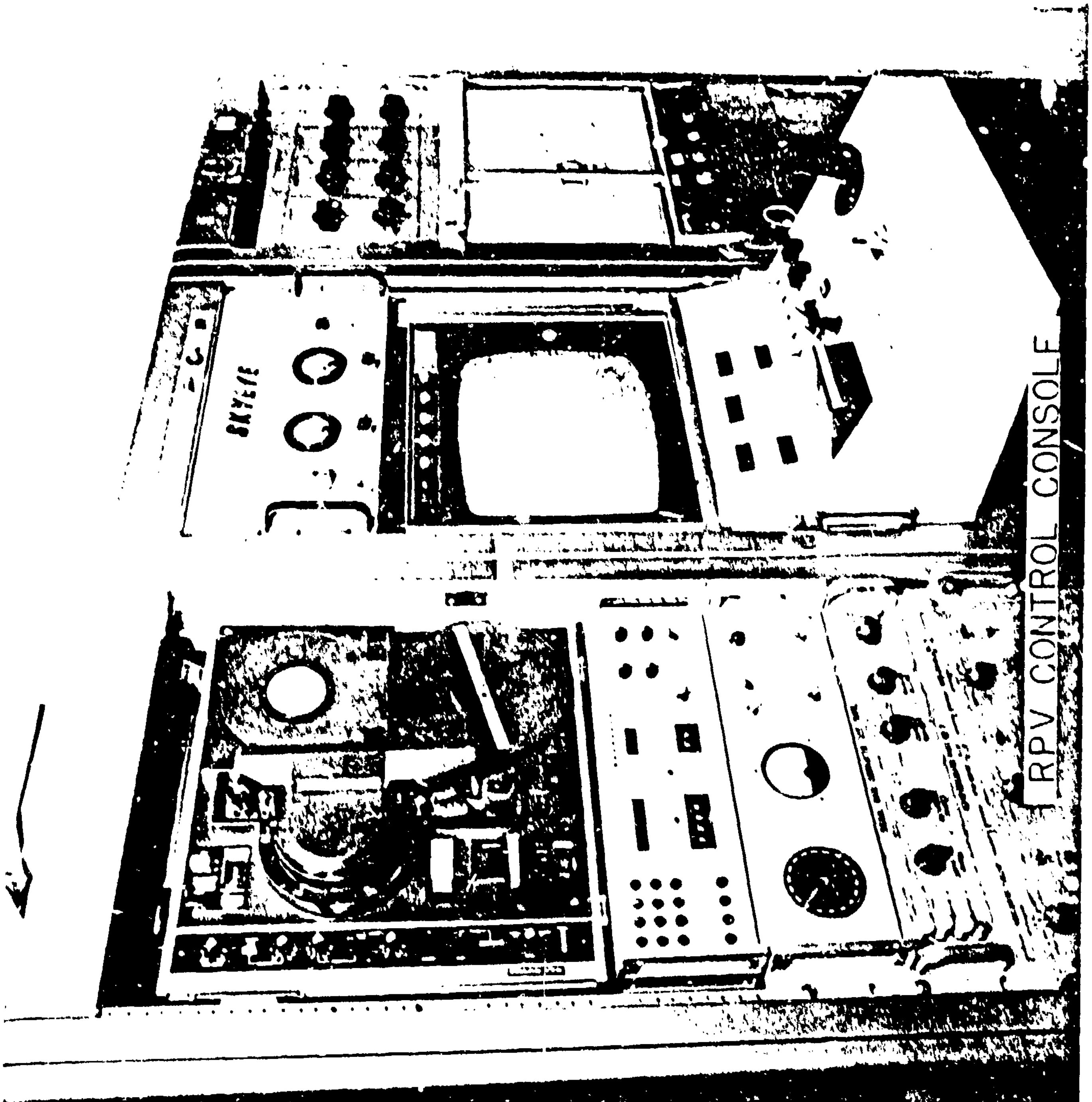


FIGURE (6)



RPV CONTROL CONSOLE

out to safe data link distance (50 miles or so depending upon line of sight antennae and transmitter power.) Real time data can be viewed at the ground station and video taped if desired. If the operator sees an area of interest the vehicle could be commanded to turn, reduce altitude and photographs could be taken if required. After completion of its patrol, the vehicle is automatically recovered in a vertical net system or landed on its landing gear.

Fixed wing mini unmanned vehicle systems will offer cost effective platforms for patrol, surveillance and monitoring through reduction of labor costs and fuel consumption. Hopefully they would also serve a prevention function and as an early warning system.

Capital costs will be highly dependent upon payload needs and production quantities, but a complete vehicle system with a video payload should cost under $70,000.00. The ground station costs will depend on sophistication, need for a dedicated tracking system, choice of launch and recovery techniques, etc. A range of costs could vary between $50,000 and $250,000. Operating costs will depend on flight hours, but will consist of expendables, operator/crew and maintenance, depreciation and insurance.

- LTA-UVS

Introduction:

A lighter-than-air unmanned vehicle system would find considerable applications in the urban area. Within their current regulations the FAA allows LTA craft to operate under 500 ft. altitude or at higher altitude with experimental waiver. The LTA-UVS offers superior safety over the FWM-UVS as well as increased endurance (at lower speeds). The class of LTA-Unmanned Vehicle Systems considered

here, would be in the 3500 ft.^{3} to 10,000 ft.^{3} size capable of carrying payloads from 80 lbs. to 350 lbs.

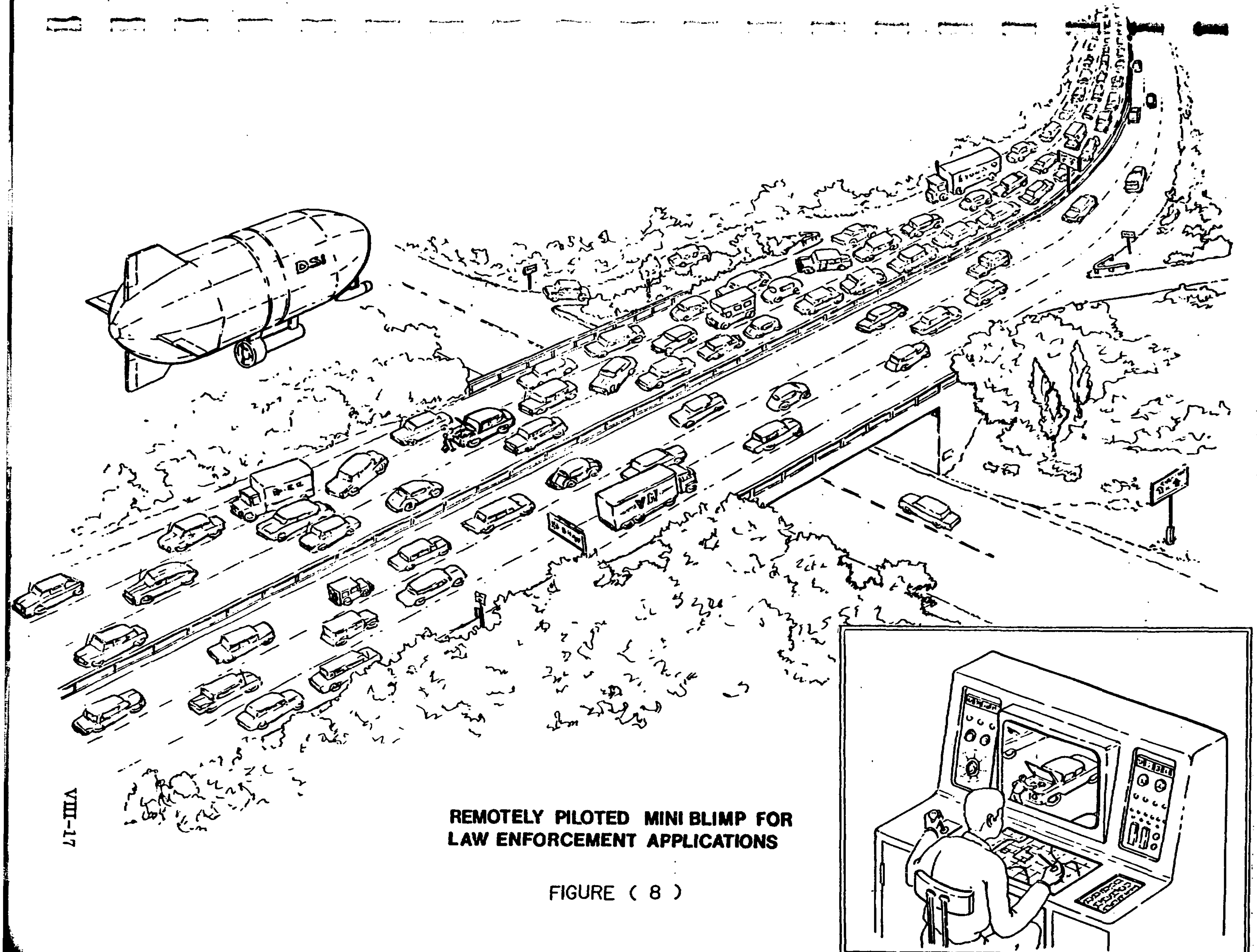
These vehicle systems could be used by law enforcement officials for traffic surveillance, industrial security patrol, search and rescue, disaster monitoring, harbor patrol, etc.* Figure 8 shows an operational concept. In the urban area fixed wing manned aircraft are carefully controlled and generally operated at 2000 ft. altitude and with higher stall speeds can not be effectively used to perform surveillance and monitoring functions. Helicopters have been used, but operational problems and costs make them prohibitive for routine operations involving many hours per day operations. With shrinking urban budgets the LTA-UVS offers an attractive system capable of performing a number of functions.

System Description

Starting in late 1973 and as shown in Reference 7 in 1974, the concept of a LTA-UVS was setforth. Several prototype systems were flown in the 1975-77 time frame.demonstrating satisfactorily the concept.[8] The mini-blimps flown proved to be very stable, easily controllable, yeilding excellent visual data (movies and video). Figure 9 shows one of the prototype systems.

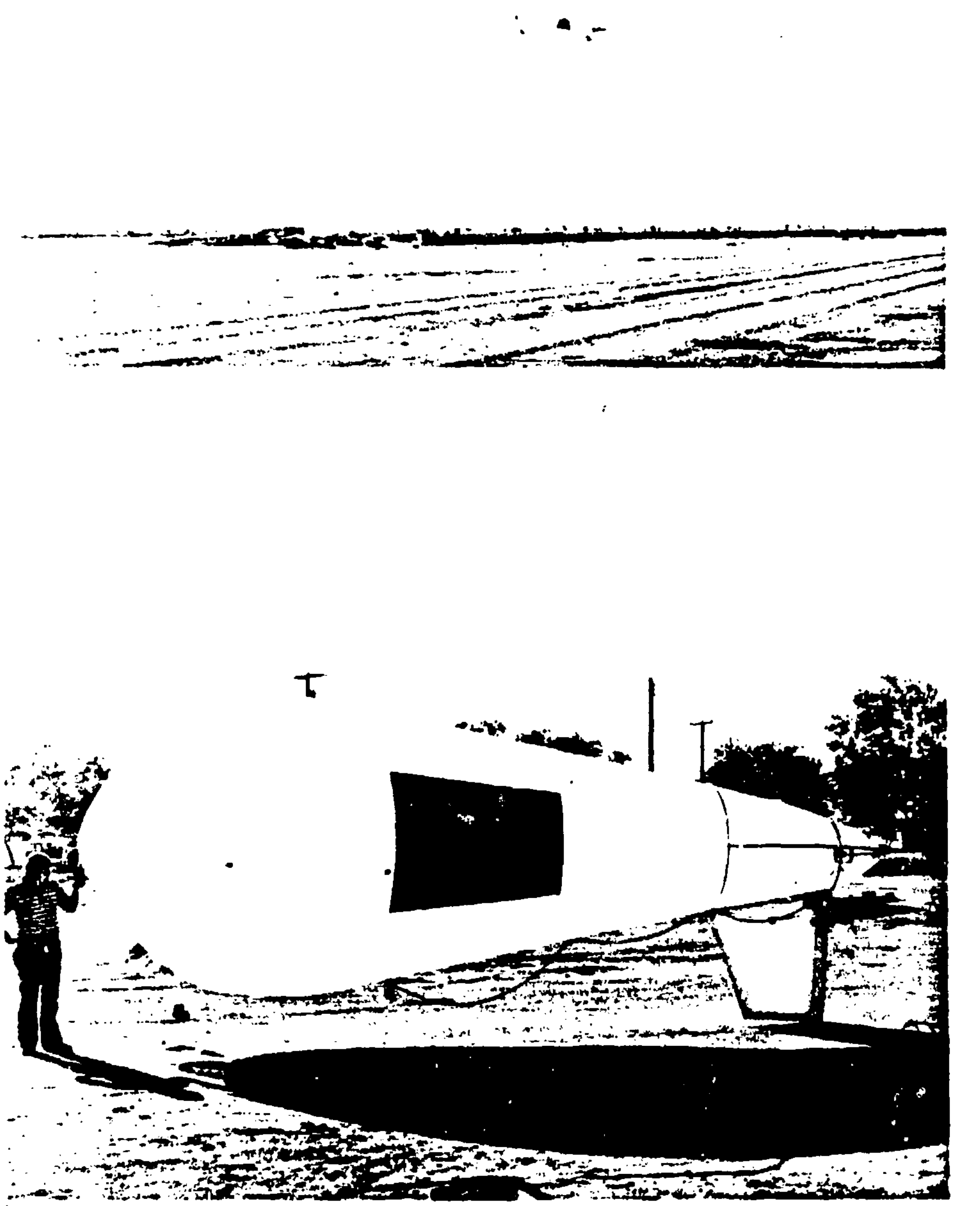
For purposes of discussion a 5000 ft.^{3} system will be briefly presented. This system will be 46 feet long and 15.3 ft. in diameter with a finess ratio of 3 and a single ballonet. This system will be capable of carrying a payload/fuel weight of 140 lbs. If 50 lbs. is used for fuel a payload of 90 lbs. can be carried. This payload could be a video system, photographic system, spot light, public address system for

*References 1 and 7 setforth other applications for the LTA-UVS.



REMOTELY PILOTED MINI BLIMP FOR LAW ENFORCEMENT APPLICATIONS

FIGURE (8)



REMOTELY PILOTED MINI-BLIMP

FIGURE (9)

example. Figure 10 shows a schematic of the 5000 ft.^{3} LTA-UVS. A weight breakdown for this configuration is;

Gross Buoyancy, msl	330 lbs.
Envelope wieght	80 lbs.
Net Buoyancy	250 lbs.
Car/propulsion pod including . . onics	110 lbs.
Payload	90 lbs.
Fuel	50 lbs.

The propulsion system can be lifted almost directly from the FWM-UVS. The flight control system is simpler than the FWM-UVS and the data links can be the same. The performance for this LTA-UVS is;

Max. speed	42 kts.
Max. endurance @ 20 kts. (50 lbs. of fuel)	20 hours
Altitude ceiling	2000 ft.

System Discussion

Launch and recovery for this size LTA-UVS is relatively easy compared to the FWM-UVS. With engine operating the LTA vehicle can take off heavy with a slight shove. Recovery can be accomplished by flying in slowly, deploying a snag line which is secured by a ground crew member. With 24 hour endurance the manpower requirements are low. The flight control system can be used to preprogram loiter or patrol modes which can be updated as required. The ground control station could be quite similar to the FWM-UVS with controls, payload sensor displays and tracking system (although normally distance of operation from the ground

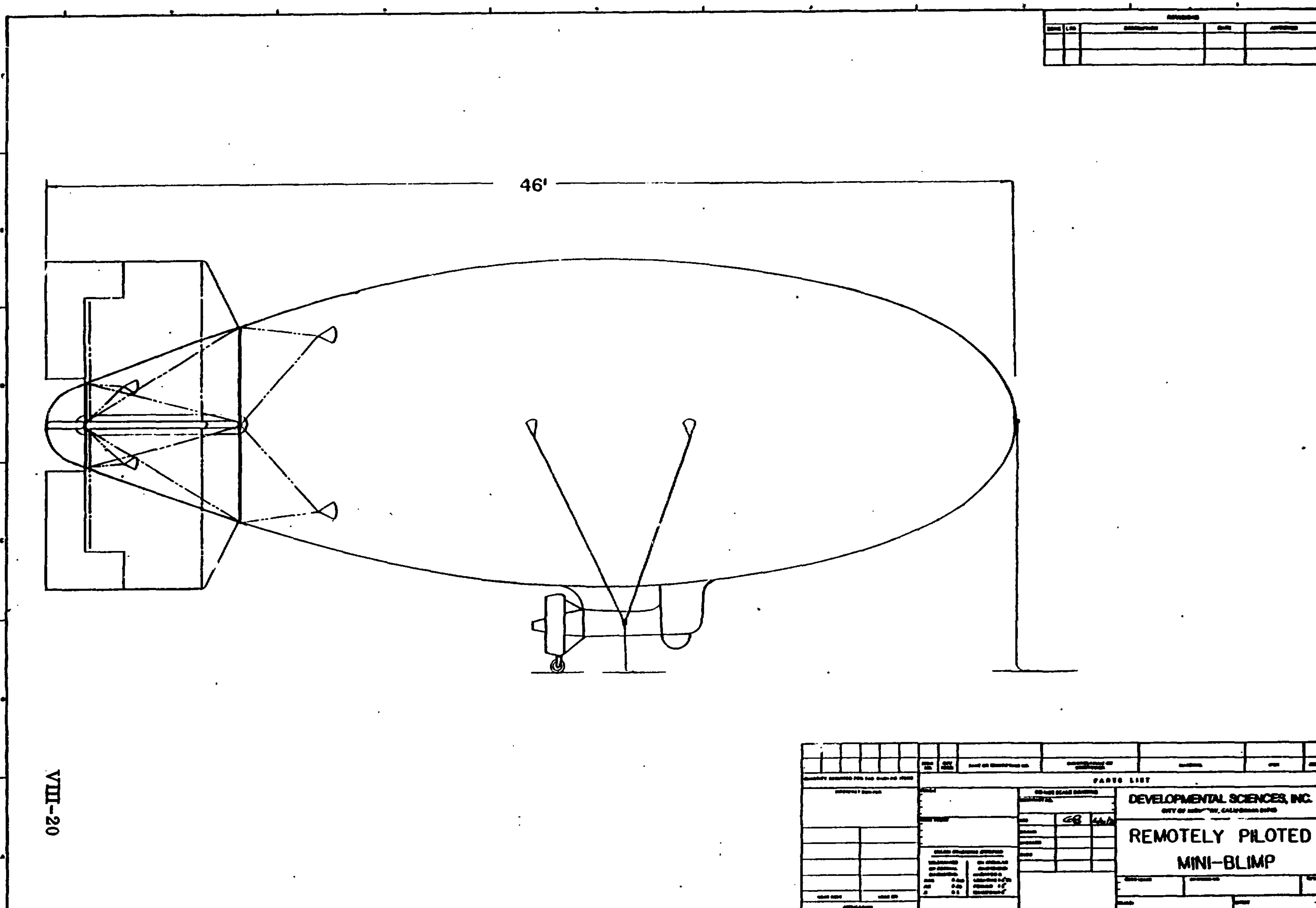

46'
PARTS LIST
DEVELOPMENTAL SCIENCES, INC.
REMOTELY PILOTED
MINI-BLIMP

FIGURE (10)

station would be considerably shorter e.g. 10 miles). Of course the LTA-UVS can essentially hover or weathercock in the wind which the FWM-UVS cannot. For many urban applications this is an operational plus.

Many helicopters are currently grounded in California due to lack of operating funds partly due to Proposition 13. The LTA-UVS offers local agencies an economical airborne platform capable of performing routine and special tasks.

Capital costs of the LTA-UVS vehicle will be approximately that of the FWM-UVS, however the ground equipment will be at the lower end of the previously presented dollar range. Operating costs per hour are expected to be less than $20/hr. including ground personnel which is a fraction of the cost to operate a helicopter. It is inherently safer, a lower polluter, relatively quite and very mobile.

Summary

The decade of the 1980's promises to be one of increasing utilization of unmanned vehicles for reasons of safety and economics. The three unmanned vehicle systems discussed in this paper were chosen as representative of those expected to be in operation during the next five years. Questions of certification, operator licensing, operating frequencies, environmental impact, insurance and liability need to addressed as part of the development and integration of Unmanned Vehicle Systems into society. The future for Unmanned Vehicle Systems looks exciting and they should at a minimum give taxpayers more for their money.

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CRUISING THE PLANETS

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Abstract

This paper describes the mission and prototypical design of an airplane which would fly at Mars, and which has applications for high altitude operations at Earth and other planets, such as Venus. As a scientific, observational, and communications relay platform, the airplane provides an excellent means of obtaining data in a resolution range intermediate to surface vehicles and orbiters. It has great versatility to perform a variety of missions: conduct aerial surveys, land instrument packages, collect samples, perform atmospheric sounding, and act as a relay/surveillance station for over-the-horizon information transmission. The airplane has many characteristics of a competition glider on Earth. Two versions of the plane have been designed: a cruiser, and one with a soft landing and takeoff capability. Maximum range and endurance on Mars are 10,000 km and 31.1 hours with a 40 kg payload.

I. Introduction

The feasibility of airplane flight at a planet other than Earth has only recently been studied seriously. In our earlier paper[1], we related the design of a plane that flies at Mars. We can consider flight there because of the tremendous increase in knowledge of the environment near the surface of Mars and demonstration of atmospheric entry by the Viking Lander. Also, steady advances in aircraft technology have brought super-lightweight structures, miniaturization of avionics, a massive increase in airborne computer capability, and and development of efficient non-air breathing propulsion systems. On this last point, of particular significance, was the invention of the single piston hydrazine engine by James Akkerman of the Johnson Space Center.

Akkerman's engine was adopted by Dale Reed[2] of Dryden Flight Research Center for his high flying Mini-Sniffer RPV. Our introduction to the Mini-Sniffer by Dr. Jose Chirivella of JPL led directly to the design of the Mars airplane. Here we shall briefly review the Mars airplane and its scientific uses. The airplane may be considered for use at Venus, Jupiter, Saturn, and Titan. We will consider adaptation and uses of the Mars airplane for high altitude flight at Earth. Indeed, this latter use is more likely to occur first, due to the recent sharp cutbacks in the Mars program by NASA.

II. The Mars Airplane

The Mars airplane configuration is very similar to that of a competition glider. Its design is constrained by several important factors. First, the air density at Mars is only about 1% that at the Earth's surface, or equivalent to the density at an altitude of 105,000 - 130,000 feet above earth. Second, there is only a very minute quantity of oxygen in the Mars atmosphere, thus requiring a non air-breathing engine. Third, to fly in such a rarefied atmosphere requires a very large wing area with a Reynolds number on the range of 4.5 to 9×10^4. This large wing area directly conflicts with the fact that the plane must be folded to fit into an entry capsule (like Viking) which must have a diameter of only about 13 feet.

Fourth, and importantly, Mars' surface gravity is only 3/8 that at Earth. This has the favorable effect of extending range by a factor of 2.65 and lower structural weight due to lowering loads. Finally, an important consideration is that speed must be modest, less than 100 meters/sec. to permit adequate time for scientific surveillance. Effectively, the higher the speed, the greater the data rate required.

The configuration which evolved from these constraints is shown in Figures (1) and (2).

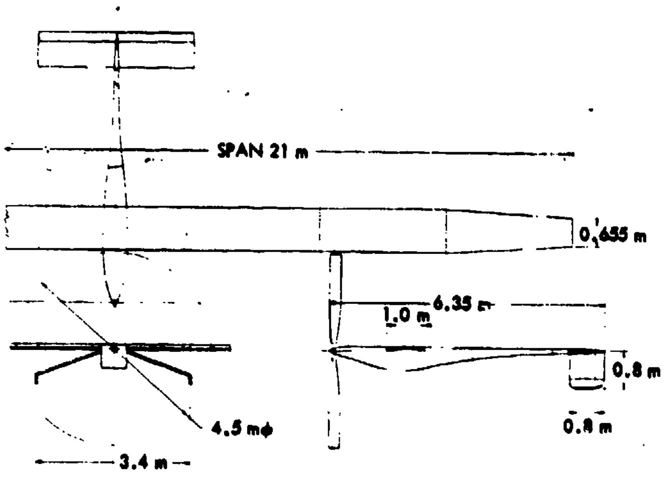


FIGURE (1) THREE VIEWS OF THE MARS AIRPLANE

STOWED GEOMETRY

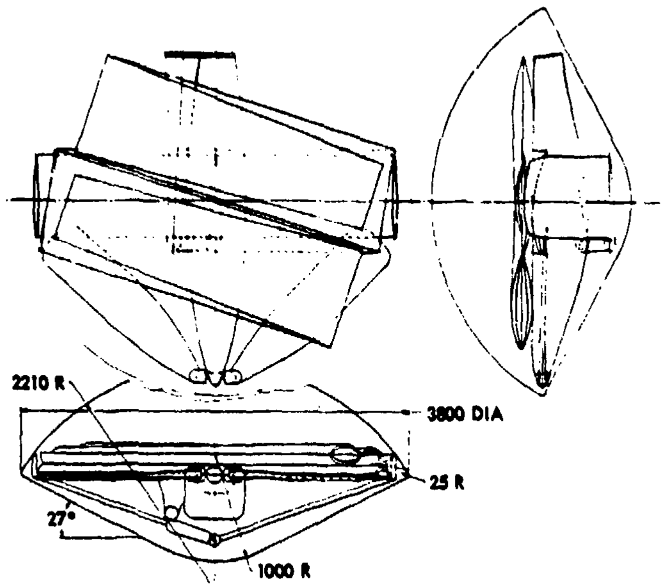


FIGURE (2) THE AIRPLANE STOWED IN A VIKING LIKE AEROSHELL

The "flat-top" fuselage with one break fold in its center, "shoulder-wings" of 20 m^2 area and 21 m span folded side-by-side with 6 breaks, fits into a slightly modified Viking aeroshell. The wing (Figure (3)) is a highly undercambered foil 5.5% thick with a structural weight of 1.5 kg/m^2. It is an epoxy composite of carbon fibers and Kevlar 49. Deployment is shown in Figure (4).

TYPICAL WING STRUCTURE

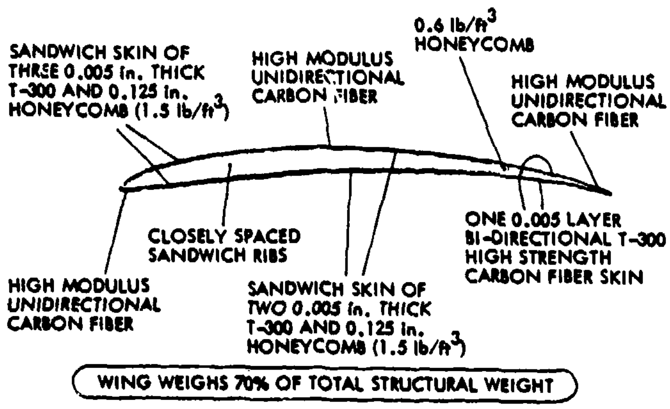


FIGURE (3) TYPICAL WING STRUCTURE USING CARBON FIBERS

For propulsion, we chose two options. The first was the Akkerman hydrazine engine and the second a samarium cobalt electric motor powered by lithium thionyl chloride batteries. Inboard profile of the hydrazine version is showed in

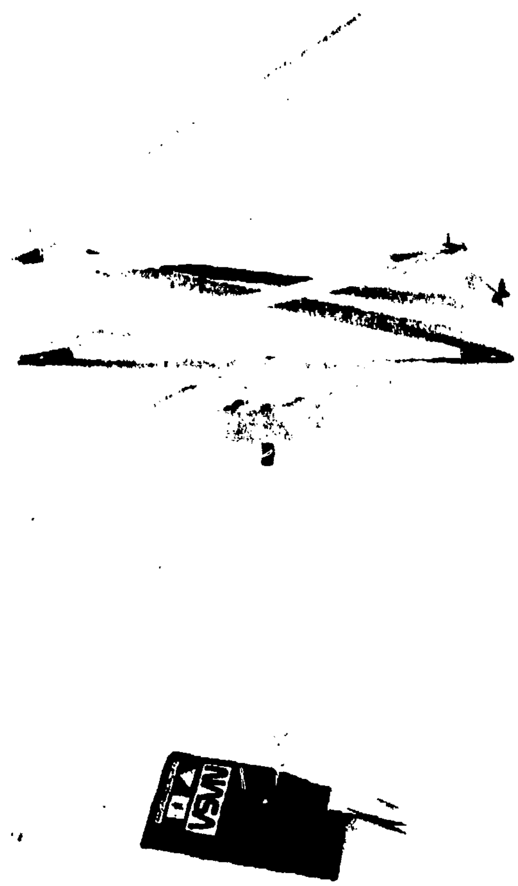


FIGURE (4) DEPLOYMENT CYCLE USING THE 1/10 SCALE MODEL

Figure (5). Here we have used the Viking Lander rockets for landing as shown in Figure (6).

A full scale forward section of the fuselage was built to determine "form-and-fit" of the 100 kg science payload, consisting of an imaging system, magnetometer, gravity gradiometer, electromagnetic sounder, gamma ray spectrometer, infrared reflectance spectrometer, gas chromatograph/mass spectrometer, infrared radiometer, and a 46 cubic cm deployable package with seismometer and meterology instruments. The all-up-weight was 300 kg with mass breakdown as shown in Figure (7). Performance of the Mars airplane (Figure (8)) for the 100 kg payload was a very respectable 5800 km (3600 mi) range with a 17.8 hour endurance.

This performance afforded excellent scientific investigation capability for imaging, search for water, atmospheric sounding, magnetic mapping, measurement of surface elements and minerals, gravity anomaly mapping, and ground temperature measurement. The plane can go anywhere on Mars, flying over rugged terrain other vehicles cannot

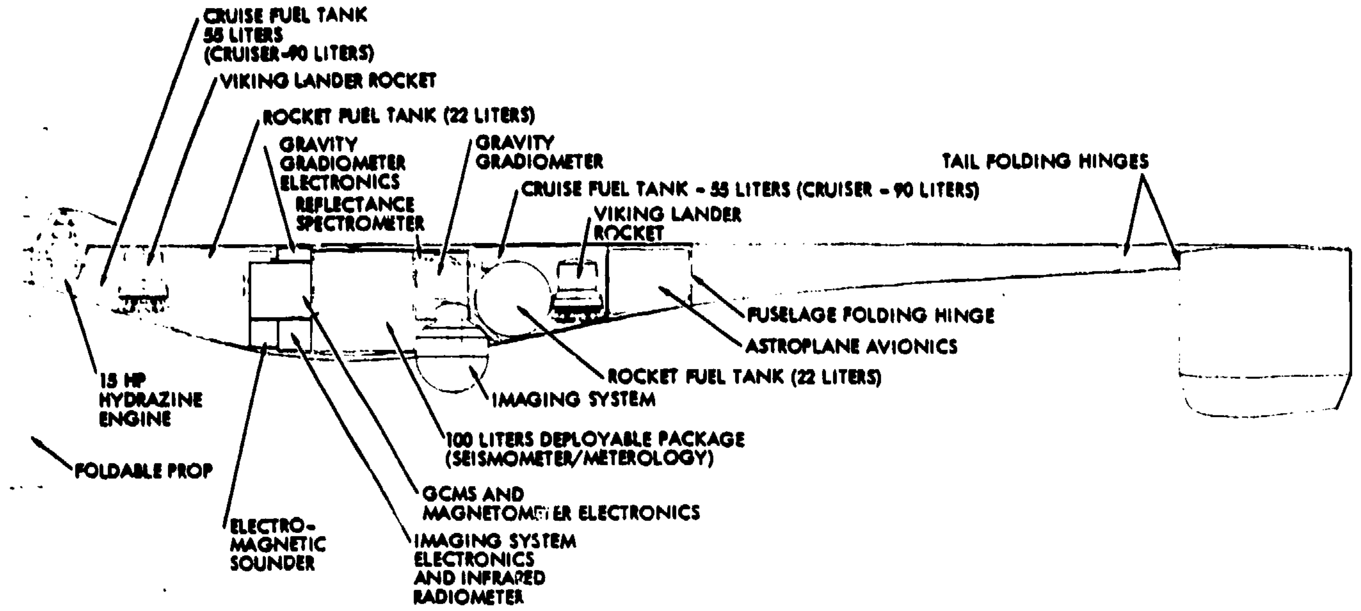


FIGURE (5) INBOARD PROFILE OF THE HYDRAZINE POWERED LANDER

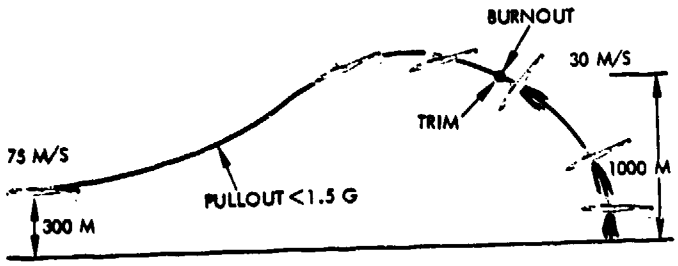
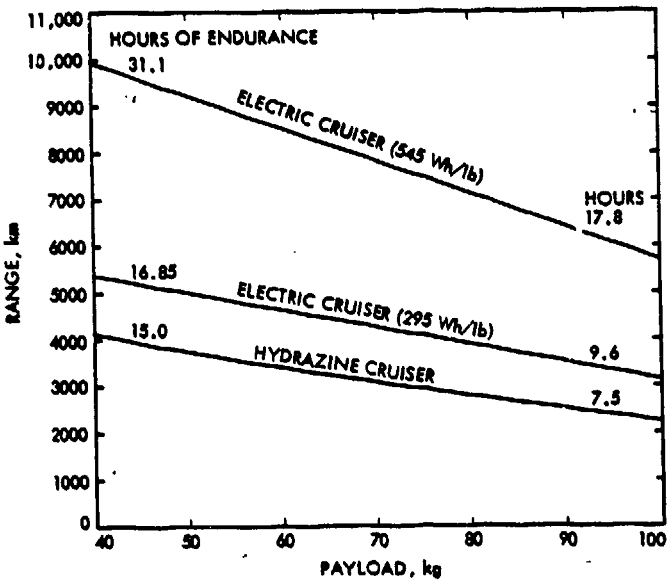


FIGURE (6) LANDING SEQUENCE USING THE DEEP STALL METHOD

	CRUISER		LANDER	
	HYDRAZ ENGINE	ELECTRIC ENGINE	HYDRAZ ENGINE	ELECTRIC ENGINE
AIRFRAME	50	50	50	50
POWERPLANT AND FUEL SYSTEM	13	20	13	20
SOLAR CELLS AND RECHARGE-ABLE BATTERY	0	0	8	8
LANDING SYSTEM	0	0	27	27
NAVIGATION, GUIDANCE, MISSION COMPUTER AND FLIGHT CONTROL	30	30	30	30
MISCELLANEOUS SYSTEMS (COMMUNICATION, ANTENNA, ENVIRONMENTAL CONTROL, etc.)	20	20	20	20
SUBTOTAL	113	120	148	155
PAYLOAD	40-100	40-100	40-100	40-100
DRY WEIGHT	153-213	160-220	188-248	195-255
FUEL	147-87	0	112-52	50-20
BATTERIES	0	140-80	0	85-25
ALL UP WEIGHT	300	300	300	300

FIGURE (7) MARS BREAKDOWN FOR HYDRAZINE AND ELECTRIC CRUISER LANDER AIRPLANES



AUW	300 kg	PROP EFFICIENCY	0.85
WING SPAN	21 m	HYDRAZINE ENGINE CRUISE SFC	4.85
WING AREA	20 m^2	ELEC MOTOR EFFICIENCY	0.85
CRUISE ALTITUDE	1 km	AUX POWER CONSUMPTION	0.4 kW
LIFE/DRAG AT 300 kg	27.75		

FIGURE (8) CRUISE PERFORMANCE FOR THE ELECTRIC AND HYDRAZINE POWERED CRUISERS

traverse. Further, it provides a one-to-two order of magnitude increase in resolution. It is a unique and versatile vehicle for scientific exploration.

III. Flight At Other Planets

As mentioned previously, an airplane may be used at Venus, Jupiter, Saturn, and Titan. Recent studies from Voyager show the satellites of Jupiter have no sensible atmosphere, so no airplane can fly there. At these other lands, the airplane's configuration would likely change drastically because they have somewhat heavier atmospheres. At Venus, for example, the air density at 50 km (30 miles) altitude is the same as at the earth's surface. The Mars airplane would fly up to 80 km (50 miles) above Venus. A suggested use by Professor Jacques Blamont of Centre Nationale d'Etude Spatiale would be as a balloon-to-balloon ferry of samples brought up from Venus' surface. Another use is as a high altitude atmospheric sounder. A likely potential power source at Venus is solar photovoltaic cells on the tops and bottoms of the wings. This is attractive because solar insolation is twice at Venus compared to earth, the very long Venusian day, and the high albedo of Venus' cloud cover.

For flight at Jupiter and Saturn, the plane may look more like a submersible and would have to withstand great turbulence.

IV. Earth Applications of the Mars Airplane

Study of the Mars airplane has prompted thought as to its value at high altitude (50,000 - 130,000 ft.) at Earth. Potential uses are:

1) As a low cost scientific instrument platform

2) A surveillance platform for military use

3) As a communication relay platform for either military use or for personal communications similar to citizens band radio.

Stationed at 21 km (70,000 ft.), the plane could view an area 780 miles in diameter, roughly the distance between the north/south borders of California. The key to its use is highly efficient propulsion to permit long endurances of the order of a month. An enticing propulsion candidate is solar photovoltaic power from cells mounted atop and on the underside of the wings. The 2 mil cells recently developed for JPL by the Solarex Corporation are a principal candidate. For the 20 m² wing area these cells would provide about 5 kw (6.7 hp) power for direct overhead sun. The principal problem is keeping the plane up at night. To do this requires rechargeable batteries with an energy density of 150-180 wh/lb. This capability is not expected until the mid 80's. Present batteries (silver-zinc) are capable of only about 60 wh/lb.

We have looked at two other options. One is the use of primary batteries with an energy density of 300 wh/lb. Endurance for this case is depicted in Figure (9). We note it is only about 17 hours at 70,000 ft. for a 20 kg payload. A substantial increase in endurance can be obtained by using a fossil fueled engine with a specific fuel consumption of 0.6 lb/hp hr (Figure 10). Here we see an endurance of 150 hours at 70,000 ft. for a 20 kg payload.

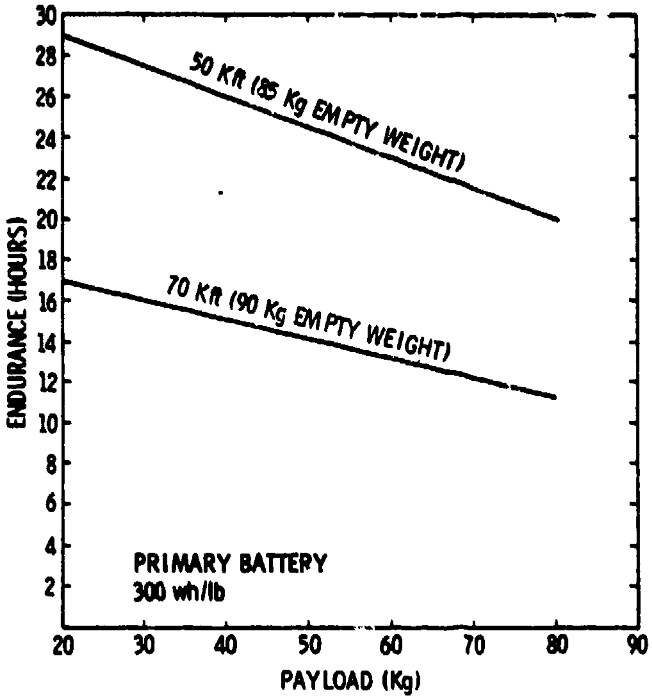


FIGURE (9) ENDURANCE vs PAYLOAD WEIGHT FOR PRIMARY BATTERIES

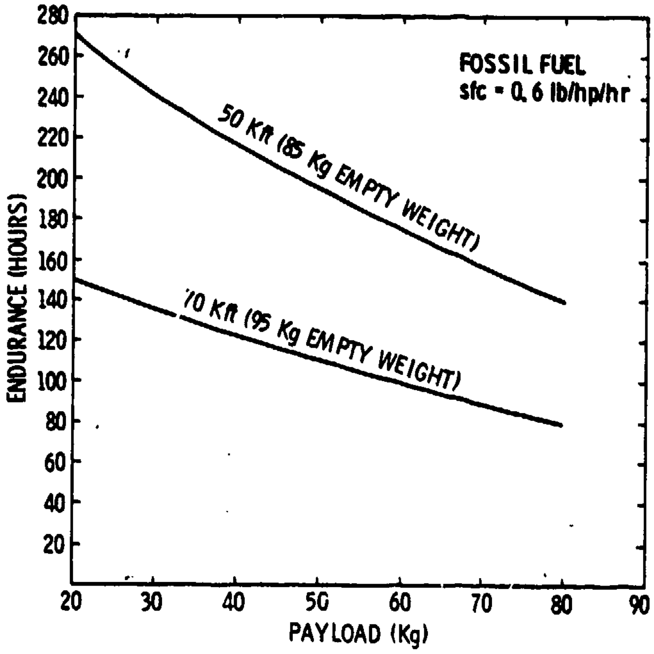


FIGURE (10) ENDURANCE vs PAYLOAD WEIGHT FOR FOSSIL FUELED POWER

V. Conclusion

Advances in aircraft technology has opened the door to airplane flight at other planets. Significantly it has also focused attention on the use of super-lightweight unmanned aircraft at high altitude at Earth. Given a threefold improvement in battery energy density within the next few years, such use at Earth for civil and military purposes is assured.

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